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BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

PROGRAMME OF THE

1954 THANKSGIVING MEETING

AT

CHICAGO, ILLINOIS

November 26 and 27, 1954

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AMERICAN PHYSICAL SOCIETY

1954 THANKSGIVING MEETING AT CHICAGO, ILLINOIS, NOVEMBER 26–27, 1954

FOR the **1954 Thanksgiving meeting** of the American Physical Society we shall enjoy, as we did last year and in many previous years, the hospitality of the University of Chicago and the administration of Mrs. Dorothy C. Johnson, to which and to whom we owe a great debt. The **dates are Friday and Saturday, November 26 and 27.** Headquarters of the meeting will be the Research Institutes building at 5630 Ellis Avenue; there our members will find the registration desk and conference rooms which will be available for intellectual and social gatherings. Probably it is unnecesstry to explain to our members the geography of the University of Chicago, but let it be mentioned that Ellis Avenue runs along the west side of the "old" campus, and the Institutes building is on its west side just north of that campus. The halls for the scientific sessions are on the old campus, except that Judd Hall lies somewhat to the east of it. The meeting promises to be somewhat bigger than last year. For instance, there are 168 contributed papers against 142. The expansion is mainly in the field of solid-state physics. Several important topics are represented on so small a scale that they have had to be lumped together under the title "general physics."

All **reservations of hotel rooms** are to be made through the **Hotels Windermere, 1642 East 56 Street, Chicago 37, Illinois. It is essential to mention the Society** in your letters asking for reservations. The Windermere East offers single rooms at $6.50 and $7.50, twin-bed rooms at $8.50 to $10.00. In the Windermere West there are singles to be had at $3.50 and $4, doubles at $5 to $6.50. Should these accommodations be fully bespoken, Hotels Windermere will assume the responsibility of finding accommodations at similar prices in other hotels of the region. This "region" is about three-quarters of a mile east of the University. The best ways to go between it and the University are by foot and by taxi. There is also a bus from 56th Street and Lake Park Avenue to 55th Street and Ellis Avenue. Those coming by rail from the East should detrain at Englewood, not downtown.

The **registration desk** will be located, to repeat, in the Research Institutes building at 5630 Ellis Avenue. All members and guests are asked to register. A registration fee of one dollar will be demanded. Consult the nearby bulletin boards for notice of post-deadline papers and of messages.

Invited papers will be given by K. A. Brueckner, Z. V. Chraplyvy, R. C. Fletcher, K. W. Ford, S. N. Gupta, A. O. Hanson, E. A. Hiedemann, R. H. Hildebrand, D. W. Kerst, Walter Kohn, J. M. Luttinger, R. G. Sachs, W. H. Studier, H. C. Urey, K. M. Watson, and B. Weinstock.

The **Division of Solid-State Physics** has arranged a **Symposium,** to be held on Saturday morning: the speakers are to be A. W. Lawson C. A. Swenson, W. Paul, and M. D. Fiske.

One hundred and sixty-eight **contributed papers** are arranged among sixteen sessions. The total number of sessions which the University of Chicago is required to house, in four half-days, amounts to twenty-one. Not many institutions could do so well for us as it has done.

The **banquet of the Society** will be held at 7:00 P.M. on Friday in the Quadrangle Club, at the southeast corner of 57th Street and University Avenue. This is an occasion when we must know *before the meeting opens* approximately how many people will attend the banquet. You are therefore strongly urged to make reservations by mail, using the form on the inside back cover page of this Bulletin. Up to noon on Friday some places may still be available for those who have not made advance reservations, but there will not be many. The price of the dinner will be $3.00, and the tickets will be sold at the registration desk. N. E. Bradbury will be one of the after-dinner speakers, and it is hoped that F. Zernike will be another. Definite announcement will be made on the bulletin boards.

Post-deadline ten-minute papers, pertaining to very recent achievements of very special importance, will be considered for admission to a special supplementary programme if the abstracts are received before Saturday, November 20, at the office of the Society. Mark these abstracts clearly for the Chicago post-deadline programme, else they will get mixed up with the abstracts for the Annual Meeting of which the deadline is the same! The titles of such papers as may be accepted will be written on the bulletin board, and the papers will be given at the end of Session E.

The **Council** of the American Physical Society will meet at 4:15 P.M. on Friday in Room 180 of the Research Institutes Building (5630 Ellis avenue) unless contrary notice is distributed to its members.

Prospective meetings and their deadlines are announced on subsequent pages of this Bulletin, as also the rules for preparation of abstracts.

Titles and abstracts of papers contributed to this 1954 Thanksgiving meeting are printed hereinafter, and in exactly this form they will reappear in a future issue of *The Physical Review*. Errata will be printed on an adjacent page of that issue if received not later than Friday, December 10, by Miss Ruth Bryans, American Institute of Physics, 57 East 55th street, New York 22, New York. Do not send in the abstract marked with corrections! Write out the corrections in the form "instead of . . . read . . ." Add nothing.

KARL K. DARROW, *Secretary*
American Physical Society
Columbia University
New York 27, New York

The 1955 Annual Meeting

The 1955 Annual Meeting of the American Physical Society will be held in New York City, on Thursday, Friday, and Saturday, January 27, 28, and 29, 1955. Assiduous readers of this Bulletin will note with sorrow the omission, from the foregoing sentence, of the once-habitual phrase "in the buildings of Columbia University." This is the first Annual Meeting of our "post-Columbia" period. The scientific sessions will be held in halls of hotels of the "Penn Zone" group, close by Pennsylvania station; and here we must give thanks to Mr. Wallace Waterfall for making these arrangements. The hotels in which we are asked to make our room reservations are the New Yorker and the McAlpin. Write at an early date to either of these, mentioning that you are a member of the Society coming for its convention. Please give your preference to these hotels. They expect it in return for conceding us their halls for our sessions, a consideration that has not hitherto been weighty in New York. If it is not granted, there may be trouble and expense in future years. The price range for rooms will be

New Yorker	
single with bath	$6.00 to $14.00
double room, one bed and bath	9.00 to 16.00
double room, twin beds with bath	10.50 to 16.00
suites, consisting of parlor, bedroom, and bath	18.00 to 50.00
extra person in room	2.50 and up
McAlpin	
single with bath	$5.25 to $9.25
double room, one bed with bath	8.50 to 13.50
double room, twin beds with bath	10.50 to 13.50
suites, consisting of parlor, bedroom, and bath	18.00 and 22.00
extra person in room	2.50

all prices subject to 5 percent occupancy tax (New York City tax)

As heretofore, this will be a convention having joint and concurrent sessions with that of the American Association of Physics Teachers. One session will comprise the Retiring Presidential Address of our President H. A. Bethe and the Richtmyer Lecture and Oersted Medal presentation of AAPT.

Deadline will be Friday, November 19, 1954. Not later than this date, abstracts must be received at the address below.

KARL K. DARROW, *Secretary*
American Physical Society
Columbia University
New York 27, New York

(**Please keep this page on file!**)

MEETINGS AND DEADLINES FOR THE SEASON 1954–1955

I. Meetings east of the Rockies and in Mexico

Place	*Meeting dates*	*Deadline date*
Chicago	November 26–27, 1954	past
New York	January 27–29, 1955	November 19, 1954
Baltimore	March 17–19	January 14, 1955
Washington	April 28–30	February 18
Toronto	June 22–24	not decided
Mexico City	about September 1	not decided

Abstracts of contributed papers for the foregoing meetings are to be sent to Karl K. Darrow, American Physical Society, Columbia University, New York 27, New York. To avoid danger of confusion, please do not send abstracts for any meeting until the deadline date of the previous meeting is past.

II. Meeting west of the Rockies

Berkeley	December 28–30, 1954	past

RULES IMPOSED ON ABSTRACTS

The Council has ordered that abstracts shall be not longer than two hundred (200) words or the equivalent thereof. In reckoning equivalence, a footnote is equated to ten words; each line in a table to ten words; a "display" formula—one that requires a line to itself—is an expensive luxury equated to forty words.

Two copies of each abstract must be sent to the appropriate office. They must be typewritten and double-spaced; one must be an original, the other may be an original or a carbon copy. Each abstract must be confined to a single page: if it is too long for a single page it is too long to be printed. Write each abstract as a single paragraph: the suppression of paragraphs costs time and labor to the editors. Look at the abstracts in this *Bulletin* to see how the title of the paper and the name of the author are to be arranged and follow the example. Issues of the *Bulletin* are sometimes appreciably delayed because the editors have to do what the authors should have done.

Remember the rule of the Council that, if an author submits more than one abstract, all but one must go onto the Supplementary Programme. In enforcing this rule, an abstract is credited to the author whose name appears first in the by-line.

EPITOME OF THE 1954 THANKSGIVING MEETING

(Personal names are those of invited speakers, except at the ends of lines where they are those of halls.)

Friday Morning at 10:00

A. Mostly theoretical physics. Cobb.

B. Neutrons. Kent.

C. Magnetism; magnetic resonance. Eckhart.

D. Hildebrand, Weinstock, Studier. Mandel.

E. Semiconductors, I; post-deadline papers, if any. Oriental.

Friday Afternoon at 2:00

G. Semiconductors, II. Oriental.

H. Radioactive nuclei; positrons. Kent.

I. Apparatus of nuclear physics; other nuclear topics. Eckhart.

K. Hanson, Watson; theoretical nuclear physics. Cobb.

L. Urey, Kerst. Mandel.

Friday Evening at 7:00

Banquet of the American Physical Society. N. E. Bradbury. Quadrangle Club.

Saturday Morning at 9:30

P. Nonmetallic solids, mostly crystals. Oriental.

Q. Mesons. Kent.

R. Reactions of transmutation, I. Eckhart.

S. Hiedemann; general physics, I. Cobb.

T. Symposium of Division of Solid-State Physics: Lawson, Swenson, Paul, Fiske. Mandel.

U. Brueckner, Sachs, Ford, Chraplyvy. Judd.

Saturday Afternoon at 1:30

V. Metals. Oriental.

W. Gupta; cosmic rays. Kent.

X. Reactions of transmutation, II: neutron-yielding reactions, electric excitation. Eckhart.

Y. General physics, II. Cobb.

Z. Fletcher, Kohn, Luttinger. Mandel.

PROGRAMME

FRIDAY MORNING AT 10:00

Cobb 110

(K. A. BRUECKNER presiding)

Theoretical Physics

A1. Quantum Theory of Noise. NORMAN ROSTOKER AND HANS EKSTEIN, *Armour Research Foundation.*—Most of the current theories of noise are semiclassical. Our approach differs in that it is entirely quantum-mechanical. It consists in formulating an operator for the spectral density of a fluctuating dynamical variable that is based on an analysis of the method of measurement. An essential feature of the spectral density operator is that it involves replacement of classical dynamical variables by time-dependent Heisenberg operators. The expectation value of the spectral density includes fluctuations of statistical origin as well as fluctuations of quantum-mechanical origin. It can be computed for any physical system when the initial state has been specified. A practical application has been made to a system in thermodynamic equilibrium. The physical system employed is similar to the one discussed by Callen and Welton[1] except that we consider degenerate eigenstates. The resultant expectation value of the spectral density of current fluctuations is in agreement with Nyquist's law.

[1] H. B. Callen and T. A. Welton, Phys. Rev. **83**, 34 (1951).

A2. Quantum Correction to the Shot Effect. HANS EKSTEIN AND NORMAN ROSTOKER, *Armour Research Foundation.*—Classically, a beam of electrons produces a fluctuating current at a detector characterized by a spectral density that is independent of frequency. The fluctuations in current are simply due to charge discreteness. Quantum corrections would be expected due to the wave-like character of the electron and due to correlation between different electrons such as is required by the Pauli principle. In this paper we consider only free noninteracting electrons and disregard the Pauli principle so that the problem can be reduced to a one-electron problem. A quantum correction is obtained whose origin is in the wave-like character of the electron. While it would be difficult to observe the quantum effect in ordinary circuits, the result is of fundamental interest. For an electron of definite momentum and kinetic energy $\hbar\omega_0$ due to motion in the x direction the spectral density of fluctuations of the current in the x direction indicates particle-like behavior for $\omega \ll \omega_0$ in which case the classical result obtains. At frequencies of the order of ω_0, the behavior is "wave-like" exhibiting a singularity in the spectral density similar to what would be expected for a photon of frequency ω_0.

A3. Quantized Linear Theory of Gravitation.* F. J. BELINFANTE AND J. C. SWIHART,† *Purdue University.*—In this year's Washington Meeting (Phys. Rev. **95**, 630 (1954), abstracts M2–M3), we have proposed a quantum theory of gravitation. This theory's Lagrangian contains the gradient of the Dirac wave function of the matter field in the interaction terms. We know of no existing general proof of the covariance of the commutation relations and of the existence of an interaction representation for a theory with such a Lagrangian. (We need the interaction representation for formulating an auxiliary condition to be satisfied by the gravitational field.) A direct proof of this covariance and of the integrability of the generalized Schroedinger equation (condition for existence of an interaction representation) is in this case rather involved. Our first attempts had negative results, as orally announced in Washington. More recently, we have found that the theory *is* Lorentz-covariant, and that an interaction representation *does* exist, if we ignore certain paradoxes which are no special features of the present theory but present themselves in every quantum field theory of the conventional type. (Compare Phys. Rev. **76**, 461 (1949), abstract H6, for a similar paradox.)

* For details, see J. C. Swihart, Ph.D. Thesis, Purdue University.
† Supported in part by the National Science Foundation.

A4. Relativistic Energy of Two-Electron Atoms. TA-YOU WU AND G. E. TAUBER, *National Research Council of Canada.*—It is shown that in the existing calculations of the relativistic corrections of the energy of helium-like atoms which are based on a perturbation treatment starting with the nonrelativistic approximation, a correction, also of the order $(v/c)^2$, has been neglected. This additional correction arises from the singular behavior of the relativistic wave functions at the origin and the failure of the usual perturbation method to take proper account of this effect up to the order $(v/c)^2$. A variational method has been suggested which is a modified form of Hylleraas' classic work so as to take account of this singular behavior. Calculations for the ground state of helium have been carried out for a 3-parameter approximation, and a correction of about $+14.5$ cm^{-1} is obtained in addition to the recent result of Sucher and Foley for the same 3-parameter approximation. The "surface integral" term found by Berestetskii and Landau and by Sucher and Foley has also been discussed on the basis of the work of Breit and of Møller.

A5. On the Infrared Divergence. F. ROHRLICH AND J. M. JAUCH, *State University of Iowa.*—The absence of infrared divergences in quantum electrodynamics in physically meaningful cross sections and related expressions is proven rigorously for any process and to all orders in the coupling constant. Two partly complementary methods are available: (a) Using the iteration solution of the S matrix the cancellation between the radiative correction and the emission of one additional soft photon can be shown explicitly to any order. (b) The collective effect of an undetermined number of soft photons can be expressed by a multiplicative factor to the basic process, which contains in closed form *all* radiative corrections. By this method, the results of Bloch and Nordsieck are found correct in a certain approximation. The divergence found by Pauli and Fierz is in contradiction with the general proof of renormalization by Dyson and Salam. This divergence is due to an unjustified extrapolation of the approximation used for the collective soft photon emission. All difficulties caused by the infrared divergences are thereby resolved.

A6. Tabulation of F Coefficients. M. FERENTZ AND N. ROSENZWEIG, *Argonne National Laboratory.*—The combination F of Clebsch-Gordan and Racah coefficients,[1]

$$F_k(LL'J'J) = (-)^{J'-J-1}[(2J+1)(2L+1)(2L'+1)]^{\frac{1}{2}} \times C_{1-1}^{LL'k} W(JJLL';kJ'),$$

occurs in the angular correlation function for $\gamma-\gamma$, $\alpha-\gamma$,

and $\beta-\gamma$ cascades. We are preparing a table of this F coefficient which will include the following range of the arguments: Integral and half-integral values of J and J' up to 12; all useful combinations of L and L' up to 6; k up to 6. The calculations are performed on Argonne's Electronic Digital Computer (AVIDAC); manual transcription of the results has been eliminated. The table will be published as an Argonne report (ANL-5324). The applicability of the F coefficient and the construction of the table will be discussed.

[1] See L. C. Biedenharn and M. E. Rose, Revs. Modern Phys. **25**, 729 (1954) and also F. Frauenfelder (to be published).

A7. Lamb Shift of the 1S Level of Deuterium. G. HERZBERG, *National Research Council, Canada.*—According to modern quantum electrodynamics, the $1S$ level of hydrogen and deuterium is predicted to lie 0.271 cm^{-1} above the energy given by the Dirac theory. In order to determine this shift experimentally, the absolute wavelength of the L_α line of D was determined by means of a 3-meter vacuum grating spectrograph in fifth order. Lines of the series 6^1S-n^1P and 6^1S-n^3P of Hg^{198} were used as standards. The wavelengths of these standards were obtained by the combination principle from lines in the visible and near ultraviolet regions. Both the lines of mercury and the line of deuterium were observed in absorption. In this way, from five independent plates the wavelength of the L_α line of deuterium has been found to be 1215.3379±0.0004 A. This value refers to an unresolved doublet. Taking account of the relative intensity of the two doublet components (2:1) and the temperature of the absorbing column (80°K), a shift of the 1^2S level of $0.25_7+0.03$ cm^{-1} results. The small deviation from the predicted value is well within the accuracy of the measurements.

A8. Fine Structure of Positronium.* R. WEINSTEIN, M. DEUTSCH, AND S. BROWN, *M.I.T.*—Previous experiments[1] on the Zeeman splitting of the 1^3S state of positronium have been extended, using 3360 mc instead of 3000 mc for the resonant frequency, and using improved methods of magnetic field measurement. The resonant value of the magnetic field was increased by 6 percent, and, within the experimental error, ΔW was found to be independent of magnetic field. Improved methods of magnetic field measurement also resulted in a decrease of the error. The best value of the singlet-triplet splitting of the ground state, calculated to order α^5 from the Zeeman splitting is $\Delta W=(2.0338\pm0.0004)\times10^5$ mc, compared with a theoretical value[2] of 2.0337×10^5 mc. A cavity has been developed to provide circularly polarized microwaves for a more accurate investigation of the degeneracy of the $1^3Sm=\pm1$ states.

[1] Weinstein, Deutsch, and Brown, Phys. Rev. **94**, 758(A) (1954).
[2] R. Karplus and A. Klein, Phys. Rev. **86**, 257 (1952).
* This work was assisted in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission, and in part by the U. S. Signal Corps and the U. S. Air Material Command.

FRIDAY MORNING AT 10:00

Kent 106

(A. S. LANGSDORF, JR., presiding)

Neutrons

B1. Neutron Spectrometer for 100–500 Kev Region. G. J. PERLOW, *Argonne National Laboratory.*—A recoil spectrometer has been constructed consisting of two closely spaced cylindrical proportional counters arranged with axes parallel. The interiors of the counters communicate via a proton collimator equivalent to a set of holes in a plate. A collimated neutron beam impinges on one counter so that forwardly directed recoils from a hydrogenous gas filling may pass through the proton collimator into the second counter. A coincidence between the two counters indicates a useful event, which is measured by the sum of the two pulse heights. The spectrum of pulse heights yields the spectrum of incident neutrons. The gas (methane) pressure is chosen for the energy region of interest, the present unit having 3.7 cm Hg. At a given pressure, the lower energy limit is reached when the collimator thickness becomes a considerable fraction of the recoil range, while the upper energy limit is determined by the total available path length. When the recoil range lies between one and two counter diameters, an asymmetric broadening appears on the low energy side of the resolution function. Pulses contributing to the tail plus pulses from higher energy events are removed by setting suitable acquirements on the ratio of the pulse heights from the two counters. With the collimator used, a trial using neutrons from $Li^7(p,n)$ gave a half-maximum line width of 14 percent at 200 kev.

B2. Neutron Transmission Measurements at the New Argonne Reactor, CP-5. L. M. BOLLINGER, D. A. DAHLBERG, R. E. COTÉ, H. E. JACKSON, AND G. E. THOMAS, *Argonne National Laboratory.*—The Argonne neutron velocity selector, used previously at CP-3′, has been modified and re-installed at the new reactor CP-5. The high flux from CP-5 made it feasible to block all but 2 of the original 6 chopper slits. This change enables us to use a 60-meter flight path. The new detector is a 4½ by 4½ inches boron-loaded liquid scintillator viewed by 4 photomultipliers. It produces a counting rate of about 4 counts per minute per μsec channel width at 1 kev and gives a high enough rate to permit full speed operation for energies above 10 ev. The mean neutron capture time in the counter of 0.4 μsec hardly influences the over-all resolution of the system, which is about 0.08 μsec/meter at full speed. The time analyzer has been made more flexible; its 100 channels may now be divided into two groups which can be independently placed to cover different flight time intervals. The total neutron cross sections of Th^{232} and U^{238} have been the first subject for investigation. All parameters of the 22, 23, and 69-ev resonances in Th^{232} and for those at 6.6, 21, 37, 66, and 102 ev in U^{238} were obtained. New structure was observed above 100 ev.

B3. Total Neutron Cross Sections in the Kev Region: Be, B, C, F, Ti, Ni, and Bi. CARL T. HIBDON AND ALEXANDER LANGSDORF, JR., *Argonne National Laboratory.*—Transmission cross sections as a function of neutron energy have been measured, by the method previously used,[1] For Be (1–55), B (1–160), C (1–160), F (1–160), Ti (1–55), Ni (1–160), and Bi (1–55); the energy range in kev is shown in parentheses. Only F, Ti, Ni, and Bi exhibit resonance structure in this energy region. The three previously known resonances in F now located at 28.2, 49.7, and 99.5 kev are found to be much

narrower and with higher peak cross sections as a result of improved resolution. The prominent features of the curve for titanium are a high peak at 18 kev with an unresolved lesser peak at 23 kev and two previously unknown peaks at 38 and 53 kev. Smaller peaks occur between 3 and 4 kev. The data for Ni are complicated, there being resonance peaks at 4.6, 5.2, 13, 16, 29, 65, 99, 111, 126, 144, and 160 kev. Of these, the ones at 16, 65, 144, and 160 kev are the most prominent. For Bi, the total cross section shows prominent resonances at 2.2, 12, 16, 34, and 47 kev with lesser ones near 4 to 5 kev. The high-energy side of a resonance below one kev was also observed.

[1] Hibdon, Langsdorf, and Holland, Phys. Rev. **85**, 595 (1952).

B4. Slow Neutron Scattering by Liquid Helium. D. G. HURST AND D. G. HENSHAW, *Chalk River Laboratories.*—Measurements of the scattering by liquid helium[1] have been continued with 1.04 A neutrons over the angular range 4.3° to 75° at several temperatures between 1.6°K and 4.2°K. The pattern shows a pronounced peak in the region of 19°. Beyond the peak the scattering falls to about two-thirds of the peak value decreasing with increasing angle with a broad weak maximum in the region of 40°. Details of the pattern vary slightly with temperature but no pronounced changes occur on going through the λ point. Transmission measurements with a gadolinium filter gave a rough indication of the energy losses accompanying scattering. At large angles the energy changes are similar to those for scattering from free helium atoms.

[1] D. G. Henshaw and D. G. Hurst, Phys. Rev. **91**, 1222 (1953).

B5. Inelastic Scattering of Neutrons by Fe, F, Mn and I.* J. J. VAN LOEF AND D. A. LIND, *University of Wisconsin.*—A collimator of a modified Preston and Stelson type has been used to define a beam of neutrons generated by the $Li^7(p,n)$ reaction. Using a neutron beam with an energy spread of 80 kev and disk scatterers of Fe, Teflon, Mn, and I gamma rays resulting from inelastic scattering have been observed with a NaI scintillation spectrometer. The excitation curve for the 850-kev gamma ray from Fe has been determined from threshold to 1.8-Mev neutron energy. The cross section at 1.2 Mev is 0.59 ± 0.06 b. In addition the angular distribution of gamma rays at 1.2 Mev was determined. The excitation curve is in agreement with Kiehn's results.[1] Excitation curves were taken for the 113 and 198 kev lines of F up to 1.8 Mev. In addition a line of 1.37 Mev was observed above a threshold of 1.57 Mev. Only one line at 126 kev was observed from Mn up to 1.2-Mev neutron energy. A preliminary value for the cross section at 1.2 Mev is $\approx 1b$. Radiations of 30, 60, 140, 200, 435, 650, and 725 kev were observed from I. A level scheme based on the excitation curve will be presented.

* Research supported by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.
[1] Kiehn and Goodman, Phys. Rev. **95**, 989 (1954).

B6. $\gamma-\gamma$ Coincidences Produced by Inelastic Scattering of 2.5-Mev Neutrons. W. R. FAUST, V. E. SCHERRER, AND B. A. ALLISON,* *Naval Research Laboratory.*—Neutrons from the $D(d,n)He^3$ reaction are used to bombard a small radiator placed inside a 1.0-inch diameter hole drilled through a 5-inch diameter by 3-inch thick NaI(Tl) crystal. Coincidences between the He^3 reaction monitor and crystal pulses gate the multichannel analyzer which records the distribution of spectrometer pulses, and thereby effectively collimates the neutrons in a narrow beam along the crystal axis. Cascade γ rays arising from neutron bombardment of the radiator produce maxima in the pulse-height distribution at their primary energy and at all possible sums of their initial energies.[1] The large crystal thus acts as a coincidence unit with a resolving time approximately equal to the decay time of the phosphor. The spectrometer efficiency for single-, double- and triple-coincidence events at 1 Mev is 40 percent, 20 percent, and 10 percent, respectively. The pulse-height distribution obtained using a Mn radiator with this spectrometer will be discussed.

* Now at University of Pennsylvania, Philadelphia, Pennsylvania.
[1] Wiedenbeck, Phys. Rev. **95** (1954).

B7. Cascade γ Rays from 2.5-Mev Neutron Bombardment of Gold, Iodine, and Chromium. V. E. SCHERRER, W. R. FAUST, AND B. A. ALLISON,* *Naval Research Laboratory.*—A coincidence γ-ray spectrometer with high efficiency for single-, double-, and triple-cascade events has been used to observe pulse-height distributions produced by 2.5-Mev neutron bombardment of gold, iodine, and chromium. The decay scheme for gold as deduced from the coincidence data shows γ rays at 0.98, 1.38, and 1.98 Mev each separately in cascade with a 0.25-Mev γ ray. There is also a 0.54-Mev γ ray not in cascade with the others. These results are consistent with previous data.[1,2] Pulse-height distributions for iodine indicate several cascade γ rays. Cr shows some cascade γ rays and is in agreement with other data.[3]

* Now at University of Pennsylvania, Philadelphia, Pennsylvania.
[1] Wiedenbeck, Phys. Rev. **68**, 1 (1945).
[2] Goldburg and Williamson, Phys. Rev. **95**, 769 (1954).
[3] Peacock and Deutsch, Phys. Rev. **69**, 306 (1946).

B8. Anomalous Absorption of Neutrons in Single Crystals. J. W. KNOWLES, *Chalk River Laboratories.*—Two nearly perfect calcite crystals, two inches thick, were set in the parallel arrangement of a two crystal neutron spectrometer and the gamma rays from neutron capture by the calcium of the second crystal were measured with a NaI scintillation detector. A maximum percentage change in gamma-ray intensity of 2.5 ± 0.6 occurred near the angle of Laue reflection. An application of the dynamical diffraction theory gave a "dispersion curve" variation with angle for the gamma-ray intensity. The theory agreed quantitatively with the experimental observation. In a second experiment concerning a search for anomalous absorption of neutrons incident at the Bragg angle, the transmission of neutrons by a 2-mm thick $3(CdSO_4)\cdot 8H_2O$ crystal was measured and compared with the transmission of x-rays. The incident radiations (1.30 A neutrons and 0.708 A x-rays) were selected by reflection from calcite crystals. When the 2-mm crystal was set near the position of Laue reflection the x-ray transmission increased from 1.5×10^{-4} to 4.5×10^{-4} but the neutron transmission decreased from 3.3×10^{-2} to 2.9×10^{-2}, this decrease being equal to the reflected intensity. Both observations could be explained by the measured mosaic block size of 0.4 mm in the crystal.

B9. Problems in the Analysis of Neutron Resonance Data.* V. L. SAILOR, H. H. LANDON, H. L. FOOTE, JR., AND R. E. WOOD,† *Brookhaven National Laboratory.*—During recent years the need for precise measurements of the Breit-Wigner parameters of slow neutron resonances has steadily increased. Ordinarily the "true" shape of a resonance cannot be directly observed because of the distortion introduced by instrument resolution, Doppler broadening, and the presence of neighboring resonances. Precise corrections for these effects are complicated and require laborious computations. Such computations, however, become practical with the assistance of modern computing machines. Methods for treating certain cases have been developed, programmed, and are in routine use on a type 409.2R Remington-Rand punched-card computer at Brookhaven. The following cases will be discussed: (1) Least squares analysis for cases where instrument resolution, Doppler broadening, and scattering can be neglected (applies generally to resonances lying in region from thermal

to ~0.3 ev); (2) Least squares analysis of the wings of a resonance including the interference between resonant scattering and potential scattering; and, (3) "Shape" analysis of the central region of resonance with corrections for instrument resolution and Doppler broadening. The results obtained from each type of analysis will be illustrated and the limitation of the methods will be discussed.

* Research performed under contract with the U. S. Atomic Energy Commission.
† Doctoral candidate at the University of Utah.

B10. Radiation Width Variations in the Neutron Resonances of Eu and In.* H. H. LANDON AND V. L. SAILOR, *Brookhaven National Laboratory.*—The parameters of the lowest energy resonances in europium and indium have been determined from total cross-section measurements using the BNL crystal spectrometer. The data have been analysed for variations of the radiation width parameter from resonance to resonance. The preliminary results are indicated in the table.

Target isotope	Resonance energy ev	Γ_γ ev
Eu^{151}	0.327	0.070
	0.461	0.093
	1.056	0.094
In^{115}	1.456	0.072
	3.85	0.087

The method of analysis used to make account of Doppler effect in the observed cross section will be presented. The limits of error of the above results will be discussed, but preliminary estimates indicate that the radiation width in the first resonance in Eu is definitely smaller than the second and third which appear most likely to be the same. The widths of the two levels in In are also significantly different. The remaining one-level parameters for each resonance will be presented.

* Research performed under contract with the U. S. Atomic Energy Commission.

FRIDAY MORNING AT 10:00

Eckhart 133

(C. P. SLICHTER presiding)

Magnetism; Magnetic Resonance

C1. A Classical Theory of the Temperature Dependence of Magnetic Crystalline Energy. CLARENCE ZENER, *Westinghouse Research Laboratories.*—An analysis has been made of the consequences of certain assumptions regarding the magnetic crystalline energy. These assumptions are: (i) the crystalline energy of a single atomic spin is a function only of its direction cosines, (ii) the only effect of temperature is to introduce deviations in these localized directions from the macroscopic magnetization direction, (iii) these deviations are the resultant of a very large number of small independent deviations, thereby giving rise to a random walk distribution function. The analysis then consists simply of taking an average of the crystalline energy using the appropriate random walk function. Upon expressing this energy as a sum of surface harmonics of the direction cosines, the coefficient E_n of the nth harmonic is found to vary as the saturation magnetization raised to the power of $n(n+1)/2$. The first harmonic satisfying cubic symmetry, beyond the zeroth order, is of fourth order, leading to the exponent of 10, in precise agreement with the observed data for K_1 of iron. An exponent of 21 is predicted for K_2 of iron. Disagreement with the data for Ni indicates the invalidity of our assumptions for this metal.

C2. Magnetic Coercive Force in Alloys of Iron and Nitrogen. J. KERR AND C. WERT, *University of Illinois.*—The increase in magnetic coercive of iron caused by the addition of two of the nitrides of iron has been measured. By appropriate heat treatment platelets of the compounds $Fe_{16}N_2$ and Fe_4N in different degrees of dispersion have been precipitated from solid solution. The course of the formation of the nitrides was followed using well known internal friction techniques. The coercive force was also measured at invervals during the nitride formation; hence it was possible to determine how the coercive force varied with the amount of precipitate which had been formed up to a given time. Electron microscope studies of the material were made to show particle shapes and sizes. The chief finding of the investigation is that the fineness of dispersion of the precipitate is of great importance in determining the coercive force increase. At least one critical particle size exists, this occurs when the largest dimension of the platelets is about 1500 A°. For platelets of this size the coercive force is a maximum. This critical dimension is about the same as the critical size found for precipitates of carbide in iron.

C3. Relation of Magnetic Structure to Electrical Conductivity in NiO and Related Compounds. R. R. HEIKES, *Westinghouse Research Laboratories.*—A qualitative theory, based on an atomic model, is presented in an effort to understand the electrical properties of NiO. Its insulating nature is shown to arise from the action of the Pauli exclusion principle. If one generalizes this theory to include all stoichiometric binary compounds, having a transition element as cation and an element from group V or VI as anion, a rather startling correlation between the magnetic and electric properties is predicted. Ferromagnetic compounds should be good conductors with a positive temperature coefficient of resistivity while antiferromagnets should be insulators with a negative temperature coefficient of resistivity. The available data indicate that this correlation does exist.

C4. Magnetic Domain Patterns Observed by the Kerr Effect in BiMn Alloy. B. W. ROBERTS AND C. P. BEAN.—The high resistivity[1] of ferromagnetic BiMn alloy allows deep penetration of light into the alloy surface which, combined with the high magnetocrystalline anisotropy, gives rise to a large magneto-optic Kerr rotation. Magnetic domain patterns are easily observed in reflection as alternate light and dark bands through nearly-crossed Nicol prisms or through the polarizing arrangement of a Bausch and Lomb metallograph. Several domain pattern types have been observed. A repetitious zig-zag or "rick-rack" pattern is usually found when the incident polarized light is nearly parallel to the C_0 axis which is also the direction of moment orientation at room temperature. In other crystallites, domain patterns are irregular and similar to those found on cobalt.[2] When light strikes a crystallite perpendicular to the C_0 axis, a system of parallel domains is observed. These propagate across grain boundaries. A

few spiral domain configurations have been observed which are not related to surface structure.

[1] K. Kondo, J. Phys. Soc. Japan **5**, 307 (1950).
[2] Williams, Foster, and Wood, Phys. Rev. **82**, 119 (1951).

C5. Antiferromagnetism of Ytterbium Sesquioxide at Liquid Helium Temperatures. WARREN E. HENRY, *United States Naval Research Laboratory.*—The study of exchange interaction between rare earth ions as related to overlap of wave functions for unpaired $4f$ electrons is of interest. The superposition of magnetic moment isotherms[1] in the liquid helium range for Ce^{+++} (in cerium nitrate hexahydrate), which has one unpaired f electron, shows smallness of exchange and negligible overlap of wave functions. The problem of studying exchange at small interionic distances, arising from the instability of Ce_2O_3, is partly solved by taking advantage of the small variation of lattice parameters among the rare earth oxides and using ytterbium sesquioxide (obtained from Professor F. H. Spedding) in which the Yb^{+++} has one unpaired hole (13 electrons in an f shell of capacity 14). Magnetization studies were carried out ballistically at 10 temperatures in the range, 1.3° to 4.2°K and in magnetic fields up to 58 000 gauss. $M(H/T)$ curves disclosed (1) nonsuperposition of magnetic moment isotherms indicating interaction and (2) positive curvature for sections of the lower temperature isotherms, indicating a possible transition. When M is plotted against temperature for fixed magnetic fields, maxima in the magnetic moment curves appeared, showing antiferromagnetism. The Néel (antiferromagnetic transition) temperature is about 2.5°K in small fields and is reduced to about 1.5°K at 30 000 gauss. At 1.5°K, 35 000 gauss suppressed the antiferromagnetism, which means that the molecular field is of the order of 35 000 gauss.

[1] W. E. Henry, Phys. Rev. **95**, 603A (1954).

C6. Relaxation Time Modification by Double Nuclear Resonance. B. HERZOG AND E. L. HAHN, *IBM Watson Laboratory and Columbia University.*—The continuous nuclear resonance of nucleus A which is coupled to a different nucleus B, whose resonance is being observed, should modify the spin-spin relaxation time T_2 of B. Since the lifetime T_2' of the B spin echo envelope depends on random fluctuations of the local field, forced reorientation of A nuclei should affect this contribution to T_2 strongly. The resonance of A ought to affect the static local field broadening, and high rate of A flipping should average it to a smaller value. Experimentally, very low and even zero field *cw* proton resonance in para-dichlorobenzene increases T_2' of Cl^{35} quadrupole echoes[1] (~34 mc) e.g., from its natural value of 1.1 ms to 5.9 ms, and produces a narrowing of the Cl^{35} static line width. The *cw* pure quadrupole resonance of Na (~400 kc)[2] in $NaClO_3$ and $NaBrO_3$ modifies T_2' for Cl^{35} (~30 mc) and Br^{81} (~150 mc) quadrupole echoes. For sufficiently large dipole-dipole Zeeman decoupling[1] of Na, T_2' passes through a minimum when the Na reorientation rate becomes comparable to the local dipolar field frequency spread of the halogen line width. Faster reorientation increases T_2' beyond its value without Na resonance. Utilizing these effects upon the halogen echo, the Zeeman splitting of the Na quadrupole interaction was measured.

[1] Bloom, Norberg, Hahn, and Herzog, Phys. Rev. **93**, 638, 639 (1954).
[2] Itoh and Kusaka, J. Phys. Soc. Japan **9**, 434 (1954).

C7. Strong Crystal Field Theory of Magnetic Resonance for d^3 Configurations. C. M. HERZFELD, *U. S. Naval Research Laboratory.*—The conventional theory of paramagnetic resonance of some ionic Cr^{+3} compounds assumes a crystal field splitting of the F state of Cr^{+3}, small compared to the separation of the free ion terms ^4F and ^4P. The splitting estimated from this theory using experimental values of g is larger than the ^4F, ^4P separation for the Cr alums and a Cr^{+3} fluoride. This paper presents calculations assuming that the crystal field breaks down Russell-Saunders coupling. Three d electrons are oriented separately in the crystal field and then coupled by electrostatic repulsion. The ground state, $^4\Gamma_2$, interacts strongly only with $^4\Gamma_5$. Angular wave functions for these levels are calculated, using a novel method based on the isomorphism of the cubic crystal rotation group with the symmetric permutation group S_4, from the idempotent generators of the irreducible representations of S_4. With these wave functions the spin-orbit coupling and external magnetic field perturbations are calculated and an equation for the effective g derived. This equation, with experimental values of g, gives crystal field splittings greater than the separation of ^4F and ^4P for the Cr alums and fluoride, and for some Mo fluorides.

C8. Nuclear Spin Relaxation in Alkali Metals Near Their Melting Points. R. E. NORBERG, *Washington University and* D. F. HOLCOMB, *Cornell University.**—Spin echo measurements of the relaxation times T_1 and T_2 previously reported[1] for metallic Li^7 and Na^{23} have been repeated (for Larmor frequencies ν_0 between 3 and 15 mc/sec), using the method of Carr and Purcell[2] to obtain T_2. In agreement with the previous results, T_2 in both metals is found to decrease suddenly upon melting. No corresponding reduction of T_1 is observed. Use of the Carr-Purcell technique excludes diffusion through magnetic field inhomogeneities as the source of the reduced T_2's found in the liquids. To test the possible quadrupolar nature[1] of the high temperature interactions, T_1 and T_2 have been measured for the Li^6 and Li^7 resonances in a metallic sample enriched to 94 percent Li^6. T_2 for both resonances decreases suddenly at the melting point. In the liquid $T_2(Li^6)/T_2(Li^7) \leq 3$, if the comparison is made at constant ν_0. This small ratio excludes quadrupolar interactions. In the liquid, T_2 for both Li^6 and Li^7 decreases as ν_0 is increased. Since the correlation frequency for the self diffusive motion in liquid lithium and sodium is much greater than ν_0, and yet $T_1 > T_2$ there, the short high temperature T_2's apparently arise either from an interaction unaffected by diffusion or from magnetic local z fields with no components effective for spin lattice relaxation.

* This work carried out at the University of Illinois.
[1] D. F. Holcomb and R. E. Norberg, Phys. Rev. **93**, 919(A) (1954).
[2] H. Y. Carr and E. M. Purcell, Phys. Rev. **94**, 630 (1954).

C9. Calculation of the g-Factor of Metallic Lithium.* P. N. ARGYRES† AND A. H. KAHN,‡ *University of California, Berkeley.*—We have performed the calculation of the g-factor of metallic lithium by means of the method of Y. Yafet.[1] This is an extension of Bardeen's method[2] enabling one to include spin-orbit interaction in the calculation of electronic wave functions in alkali metals. Seitz's empirical potential for the lithium atom[3] was used to represent the potential within the W.-S. sphere. The result obtained for the shift from the free electron g is $\delta g = -3.0 \times 10^{-5} \sin^2\theta_0$, where θ_0 is the angle between the electronic wave vector and the magnetic field. A perturbation calculation based on plane waves gives a result an order of magnitude smaller than that of the above method. Experimental measurements of the g-factor of metallic lithium have been performed by Feher.[4] He finds $\delta g < 10^{-4}$; the shift is too small to be measured at present.

* This research has been assisted in part by the Office of Naval Research and the U. S. Signal Corps.
† Now at Westinghouse Research Laboratories.
‡ Now at Department of Physics, University of Illinois.
[1] Y. Yafet, Phys. Rev. **85**, 478 (1952).
[2] J. Bardeen, J. Chem. Phys. **6**, 367 (1938).
[3] F. Seitz, Phys. Rev. **47**, 400 (1935). We are indebted to Professor J. Bardeen for providing the correct potential used by Professor Seitz.
[4] G. Feher, Phys. Rev. (to be published).

FRIDAY MORNING AT 10:00

Mandel Hall

(W. H. ZINN presiding)

Invited Papers

D1. The Use of Glaser Bubble Chambers in Photographing Nuclear Events. R. H. HILDEBRAND, *University of Chicago.* (30 min.)

D2. Nuclear Alignment in Liquid Helium 3. B. WEINSTOCK, *Argonne National Laboratory.* (30 min.)

D3. Nuclear Properties of Elements 98, 99, 100. W. H. STUDIER, *Argonne National Laboratory.* (30 min.)

FRIDAY MORNING AT 10:00

Oriental 104

(RALPH BRAY presiding)

Semiconductors, I

E1. Oscillatory Hall Effect, Magnetoresistance, and Magnetic Susceptibility of a Graphite Single Crystal. TED G. BERLINCOURT AND M. C. STEELE, *United States Naval Research Laboratory.*—Oscillatory dependences upon magnetic field at low temperatures have previously been observed in the magnetic susceptibility (de Haas-van Alphen effect) of a graphite single crystal by Shoenberg[1] and in the magnetoresistance by Berlincourt and Logan.[2] We have observed oscillations in the Hall coefficient as well and have also measured the magnetoresistance and magnetic susceptibility of the same graphite crystal at liquid helium temperatures in magnetic fields up to 25 kilogauss. In all cases the oscillations are periodic in reciprocal field and exhibit the same period $\beta/E_0=2.15\times10^{-5}$ gauss^{-1} for the magnetic field parallel to the hexagonal axis. The phases, however, are different in that magnetoresistance minima lag minima in diamagnetism by approximately $\pi/2$ in reciprocal field, while Hall coefficient minima lag minima in diamagnetism by roughly $\pi/4$.

[1] D. Shoenberg, Trans. Roy. Soc. (London) **A245** (1952).
[2] Ted G. Berlincourt and John K. Logan, Phys. Rev. **93**, 348 (1954).

E2. Donor Impurities in Graphite. G. HENNIG AND M. DZURUS, *Argonne National Laboratory.*—In graphite, the nearly empty conduction and nearly full valence bands barely touch or possibly overlap very slightly; therefore graphite is intermediate in properties between metals and semiconductors. The electrical properties of graphite, like those of real semiconductors, are sensitive to the presence of those impurities which charge the electron population of the band structure. The impurities can be introduced at lattice imperfections in clusters of about three to five, but only one in such a cluster will ionize. They can also be introduced in two-dimensional layers between the graphite layer planes (so-called lamellar compounds), but even then only about one in four will ionize. The ionized fraction is very nearly temperature-independent. Because of the fractional ionization, acceptors and donors can be studied quantitatively only if they can be introduced electrolytically. Such a study has been described earlier by us for acceptors.[1] Donors can be introduced electrolytically in liquid ammonia. The effect of these added donors on the Hall coefficient, resistance, and magnetoresistance will be described. The results seem to confirm the calculations of Carter and Krumhansel,[2] which predict that the valence and conduction bands are not symmetrical at the zone boundaries.

[1] G. Hennig, J. Chem. Phys. **19**, 922–29 (1951).
[2] J. L. Carter and J. A. Krumhansel, J. Chem. Phys. **21**, 2238 (1953).

E3. Electronic Relaxation Time in Graphite. JOHN E. ROBINSON, *Argonne National Laboratory.*—The major contributions to the electronic transport properties of graphite come from electrons whose kinetic energy to the first approximation is not a quadratic function of wave number but is more nearly proportional to the modulus of the wave number vector as measured from the edge of the first Brillouin zone. As a pilot investigation, the elastic, incoherent scattering by a Coulomb field of electrons in a two-dimensional graphite layer is discussed. The kinetic energy relative to the band edge is proportional to $|\mathbf{k}|$, where $\mathbf{k}$ is measured from a zone corner. The condition for the validity of treating the scattering in terms of orbital concepts is independent of electronic energy. The relaxation time appropriate to current decay is found to be independent of electronic energy.

E4. Electrical and Optical Properties of GaSb Films. R. J. COLLINS, F. W. REYNOLDS AND G. R. STILWELL, *Bell Telephone Laboratories.*—Films of gallium antimonide were prepared by evaporation of the compound from shallow tungsten heaters. The deposition was carried out at pressures below 10^{-5} mm of Hg onto a warm (100°C) glass substrate and completed in 3–5 sec. Before the films were removed from the vacuum they were annealed for four hours at 450°C. Electron diffraction studies showed only the structure of the compound. The films were shown to be continuous and to have crystallite size of 600–1000 A with the electron microscope. All films prepared to date were p type with room temperature resistivities and Hall coefficients of 0.05–0.5 ohm cm and electron mobilities of $\sim$50 cm^2/volt sec, respectively. The transmittance and reflectance were determined from 0.5 to 3.0 microns. With the film at room temperature, using chopped radiation, photoconductivity was observed for wavelengths shorter than 1.8 microns. The half-response point corresponded to an energy of 0.75 ev. When cooled to 77°K the response increases and shifts to shorter wavelengths, from which a temperature dependence of the energy gap can be calculated to be $\sim3\times10^{-4}$ ev/°C.

E5. Usually Large Magnetoresistive Effects in InSb for Specialized Boundary Conditions.* R. K. WILLARDSON, T. C. HARMAN, P. F. CHOQUARD, AND A. C. BEER, *Battelle Memorial Institute.*—In the usual determination of transverse galvanomagnetic effects, the boundary condition $j_y=0$ is applied. If less restrictive transverse boundary conditions are realized, interesting phenomena are observed in high-mobility semi-

conductors. One example is the behavior of the Hall-effect gyrator.[1] Another is the greatly augmented magnetoresistive effects discussed by Weiss and Welker,[2] particularly those resulting from the geometry of the Corbino disk. For large values of μH, simplified analysis gives $\Delta\rho/\rho_0 \cong (9\pi/32)\mu_0^2 H^2$. This would predict values for $\Delta\rho/\rho_0$ of greater than 300 at 80°K and 10 000 gauss for the hyperpure specimens of InSb in which electron mobilities of over 200 000 cm²/sec-volt were measured. However, for such large magnitudes of μH, electron orbit quantization effects should probably be taken into account[3] in the formulation of the Boltzmann equation. Calculations are compared with experimental data as a function of magnetic field at several temperatures.

* Supported in part by Wright Air Development Center.
[1] R. F. Wick, J. Appl. Phys. **25**, 741 (1954).
[2] H. Weiss and H. Welker, Z. Physik **138**, 322 (1954).
[3] A. H. Wilson, *The Theory of Metals* (Cambridge University Press, Cambridge, 1953), p. 210.

E6. The Crystal Structure of Indium Bismuthide. W. P. BINNIE, *Purdue University.**—Indium bismuthide prepared by L. M. Roth by fusing in a melt equal atomic proportions of each element. From single-crystal analysis the structure is shown to be the B-10 type,[1] the most well-known example of which is PbO. The tetragonal unit cell has dimensions $a=b=4.999$ A and $c=4.773$ A and contains two molecules of InBi. Extinctions are consistent with the space group $P4/nmm$. The In atoms are located at (0,0,0) and $(\frac{1}{2},\frac{1}{2},0)$ and the Bi atoms at $(0,\frac{1}{2},Z)$ and $(\frac{1}{2},0,\bar{Z})$ with $Z=\sim 0.39$, so that each In atom is surrounded tetrahedrally by four Bi atoms and each Bi atom is bonded to four In atoms which form a square on one side of it.

* Work supported by Signal Corps contract.
[1] Struktur Bericht **1**, 89 (1913–1928).

E7. Semiconducting Properties of Iron Oxide Thermistor Material.* J. J. BROPHY, N. ROSTOKER, AND L. V. AZAROFF, *Armour Research Foundation.*—The semiconducting properties of iron oxide thermistor material containing 10 percent each of copper and titanium ions as impurities have been examined. This material, prepared by sintering the oxide powders, is found to have the crystal structure of alpha Fe_2O_3, indicating simple substitution of copper and titanium for iron ions in the lattice. The resistivity is a logarithmatic function of temperature having an activation energy of 0.52 electron volt. Hall effect and Seebeck effect studies of the semiconductor show that this variation is due to thermal activation of carriers to conduction levels. The carriers are found to be electrons with mobility of about 1.0 cm²/volt second. Concurrent with the origin of electrical conduction is ferromagnetic behavior, and a saturation magnetic moment of 2.0 emu/g at room temperature is observed above magnetic saturation at about 5000 oersteds. A discrepancy between donor concentration determined from extrapolated carrier density measurements and the known concentration of impurity atoms appears to indicate a type of cancellation between the effect of copper and titanium atoms.

* Work supported by Bureau of Ordnance, Department of the Navy.

Post-Deadline Papers, if Any

FRIDAY AFTERNOON AT 2:00

Oriental 104

(WALTER KOHN presiding)

Semiconductors, II

G1. Pressure Dependence of Absorption Edge in Germanium and Silicon. W. SPITZER, C. O. BENNETT, AND H. Y. FAN, *Purdue University.**—The effect of pressure on the edge of fundamental absorption in the near infrared was investigated for germanium and silicon up to 1000 kg/cm². The samples were placed in a chamber with windows and with dry nitrogen under pressure. For germanium, the edge (up to an absorption coefficient of 100 cm⁻¹) showed a parallel shift to higher energies under pressure, amounting to $(8.2\pm1)\times10^{-6}$ ev kg⁻¹ cm². The absorption edge in silicon showed similar behavior with a shift of about 5×10^{-6} ev kg⁻¹ cm²; this result is less accurate than for germanium. The value for germanium is comparable to but somewhat larger than the pressure coefficient of energy gap, about 5.5×10^{-6} ev kg⁻¹ cm², deduced from the variation of intrinsic resistivity.[1] Such results are not available for silicon. Shifts of the absorption edge with temperature for silicon and germanium have been measured by M. Becker[2] and others in this laboratory: -5×10^{-4} ev/°K for germanium and -4.5×10^{-4} ev/°K for silicon. According to the observed pressure shifts, the effect of lattice dilation accounts only for a small fraction of the temperature shift.[2]

* Work supported by a Signal Corps contract.
[1] See W. Paul and H. Brooks, Phys. Rev. **94**, 1128 (1954), and references given there.
[2] H. Y. Fan, Phys. Rev. **82**, 900 (1951).

G2. Single-Crystal Layers of Germanium Semiconductors. W. M. BECKER AND K. LARK-HOROVITZ, *Purdue University.**—Using grinding and etching techniques, germanium layers a few microns thick have been prepared from single crystals. X-ray diffraction indicates that these layers are single crystals. Whereas germanium films deposited from the vapor are always p type with abnormally small mobilities (1–150 cm²/volt sec), these single-crystal layers, like the bulk material they are made from, are n type or p type with mobilities comparable to bulk material of the same resistivity. These films having been mounted in a high vacuum opposite a polonium source, conductivity and Hall effect are measured as a function of alpha particle irradiation. Both n-type and p-type material varying in resistivity from 0.01 ohm-cm to 30 ohn-cm have been investigated. The efficiency of carrier removal depends on the position of the Fermi potential at the start, being highest for the lowest resistivity material. Both hole and electron traps are introduced by irradiation as indicated by the initial resistivity increase of both n-type and high-resistivity p-type samples. The efficiency for electron removal is far greater than for hole removal.

* Supported by a Signal Corps contract.

G3. Low-Temperature Electrical Conductivity of Germanium. S. H. KOENIG AND G. R. GUNTHER-MOHR, *IBM Watson Laboratory.*—The variation of current with applied voltage in germanium crystals at liquid helium temperatures has been measured. The variation is ohmic at very low voltages, then has a region in which the logarithm of the current is linear in voltage, followed in turn by a negative resistance region in which the current increases orders of magnitude for

very small changes in voltage. The dependence on temperature, the importance of surface treatment, nature of contacts, and geometry will be discussed. The conduction thus resembles that of gas discharges at low pressure except that the current density depends only on the applied field for sample thicknesses from 10^{-2} to 1 cm. Previous observations[1] have been interpreted as due to carrier multiplication by collision ionization of impurity centers. Preliminary measurements of both "ionization" and "deionization" time show them to be less than 5×10^{-7} sec. The initial investigations were undertaken by Dr. P. J. Price and Dr. G. L. Tucker of this laboratory.

[1] E. M. Conwell, Phys. Rev. **94**, 1068 (1954); Dresselhaus, Kip, and Kittel, Phys. Rev. **92**, 827 (1953); Sclar, Burstein, Turner, and Davisson, Phys. Rev. **91**, 215 (1953).

G4. The Segregation Coefficient of As in Germanium as a Function of Crystal Growth Variables.* D. C. JILLSON AND A. C. SHECKLER, *General Electric Electronics Laboratory.*—The segregation coefficient of arsenic during the growth of single crystals of germanium has been studied as a function of the orientation, the growth rate, and the temperature gradient across the liquid-solid interface. For a given low temperature gradient, values of the segregation coefficient for ⟨111⟩ and ⟨112⟩ orientations differ at all growth rates studied (down to ½ inch per hour) and are converging on a zero rate value of about 0.02. This is contrary to previously published data presumably taken at higher temperature gradients. At higher rates of growth, a log-log plot of carrier concentration *vs* weight fraction not pulled departs from linearity, indicating that the segregation coefficient is not constant. Reasons considered for this departure from theoretical assumptions are inadequate stirring, appreciable solid-state diffusion, gain or loss of impurity, segregation of a second impurity, and crystalline imperfection.

* This work was supported by Air Force Contract.

G5. Minority Carrier Lifetime as a Function of Crystal Growth Variables.* A. C. SHECKLER AND D. C. JILLSON, *General Electric Electronics Laboratory.*—Lifetime of minority carriers in N-type germanium has been studied as a function of the crystal growth rate and of the temperature gradient in the region of the liquid-solid interface during growth. For a given low temperature gradient the recombination center density increased for a high rate of growth and remained constant or decreased for lower growth rates. Available data indicate the same effect with a steeper gradient, but at different growth rates. Simple segregation of an impurity atom cannot account for the observed variation in recombination center density.

* This work was supported by Air Force Contract.

G6. Minority Carrier Extraction in Germanium. RALPH BRAY, *Purdue University.**—Application of an electric sweep field to high-resistivity Ge samples with low resistance end contacts produces a decrease or increase in sample resistance, corresponding to propagation by drift of an excess (injection) or deficiency (extraction) in concentration of minority carriers along the sample from the forward biased contact. Which effect is observed should depend on whether the equilibrium concentration of minority carriers at the contact is greater or less than in the interior. This is determined by the method of making the contact. With increasing field in extraction, and for transit times$\ll$lifetime, the increase in resistance saturates at a value corresponding to less than total minority carrier extraction. For a 25 ohm-cm p-type sample, extraction shifts the peak in resistivity *vs* temperature from 297° to 327°K. Increases in resistance $\leq$factor of 3 were observed in the near-intrinsic range. Measurements of lifetime on the same sample, whether from observation of transient recovery after extraction or after injection, are in good agreement, as would be expected for recovery after extraction by thermal generation. Extraction may be applied for modulation of diodes and transistors and extension of temperature and power range of their operation.

* Work supported by Signal Corps Contract.

G7. (Abstract withdrawn.)

G8. The Hall Coefficient in Anisotropic Media.* E. G. GRIMSAL,† *Louisiana State University.*—An expression has been obtained for the Hall coefficient in the case of the anisotropic two-band model. The derivation is classical, except inasmuch as the interaction of the electrons with the lattice is included by the use of effective masses. The absence of integrals over the Fermi surface permits the retention of the anisotropy of the effective masses. When the anisotropy is neglected, the expression obtained in the case of vanishing magnetic field reduces to the expression usually given for the Hall coefficient for small fields.

* Supported in part by the National Research Council.
† Now at Canisius College.

G9. A Physical Model of Semiconductors. J. G. BARREDO,* *Instituto Rocasolano, Consejo Superior Investigaciones, Madrid.*—A physical model of semiconductors described by the equation $I=zFK\Sigma^{\alpha}(4qzd/m)^{\frac{1}{2}}N^{\alpha}t^{-\frac{1}{2}}+V/R$ is given (I=current; z and q=charge of the dipole and carrier, respectively; d=half of the length of the dipole; m=mass; t=time; α=order of the reaction; K=constant; F=faraday).[1] It was verified experimentally, with oscillographic precision, for germanium diodes and diffusion junction rectifiers between liquid nitrogen temperature and 300°C. It describes how current can be increased by increasing the number of dipoles Σ or carriers N by nuclear bombardment or other means.

* c/o Jones Laboratories, University of Chicago, Chicago, Illinois.
[1] Preliminary work, J. G. Barredo, Phys. Rev. **83**, 243 (1951); J. Chem. Phys. **19**, 1065 (1951).

G10. Theory of the Magnetic Rectifier.* KURT LEHOVEC, ALMA MARCUS, AND KURT SCHOENI, *Sprague Electric Company.*—A theoretical investigation was made of the rectifying properties of a slab of intrinsic semiconducting material placed in crossed electric and magnetic fields, when opposite sides are treated to give widely different surface recombination velocities. Surface and volume recombination rates were assumed to be linear functions of the deviation from equilibrium carrier densities. It was concluded that saturation values are reached in the case of forward as well as reverse currents at large electric fields. The ratio of the saturation currents equals the ratio of the surface recombination velocities. Both saturation values are inversely proportional to the magnetic field in-

tensity. The derivation of surface and volume recombination constants from measurements of the current voltage characteristic will be discussed.

* Work carried out in part under contract with the U. S. Army Signal Corps.

G11. Verification of the Bridgman Relation for a Mixed Semiconductor. G. M. SEIDEL AND V. A. JOHNSON, *Purdue University.*—It has been shown that the Lorentz solution of the Boltzmann equation for a semiconductor containing both electrons and holes leads to a set of current density equations whose coefficients satisfy the Onsager relation; and consequently the Bridgman relationship $T\eta_i=\kappa_i P$ holds, where T, η_i, κ_i, P are, respectively, the temperature, isothermal Nernst coefficient, isothermal thermal conductivity, and Ettingshausen coefficient. With the assumed independence of electrons and holes, the current density equations are put into the form used by Callen;[1] the current densities used are the electric current density and the heat current density defined by $Q=TS$ where S is entropy current density. The various coefficients need not be evaluated to show that the Onsager relations hold, but can be left in the integral form as functions of energy, mean free path, and Fermi-Dirac distribution function. Once it is verified that the coefficients of the current density equations do satisfy the Onsager relation, the Bridgman relation follows automatically.

[1] H. B. Callen, Phys. Rev. **73**, 1349 (1948).

G12. Generalized Deformation Potential Theory for *n*-Type Ge.† WILLIAM P. DUMKE, *University of Chicago and Chicago Midway Laboratories.* Introduced by E. N. Adams, II.—The deformation potential theory has been re-examined taking into account the ellipsoidal shape of the surfaces of constant energy in reciprocal lattice space, and the effect of shear-wave scattering in n-type Ge. We find that if scattering by compressional waves is the dominant scattering process, a simple relaxation time exists proportional to $E^{-\frac{1}{2}}$, just as for spherical energy surfaces. However, the scattering due to shear waves is strongly anisotropic and cannot be described by a simple relaxation time. We have been able to show that when shear wave scattering is taken into account, the distribution function for electrical conduction takes the usual form $f_1=-e\mathbf{E}\cdot\langle\bar{\tau}\rangle\ddagger\cdot\nabla_p f_0$, except that the relaxation time is a second rank tensor with components that depend on direction. Preliminary calculations indicate that shear-wave scattering is the dominant scattering mechanism for n-type Ge.

† This research was supported in part by the United States Air Force.
‡ This notation is used in place of the authors' tau with a double bar, which the printer does not have.

FRIDAY AFTERNOON AT 2:00

Kent 106

(R. M. STEFFEN presiding)

Radioactive Nuclei; Positrons

H1. Gamma Rays from Proton Bombardment of Li^6.† S. BASHKIN AND R. R. CARLSON, *State University of Iowa.*—A NaI scintillation spectrometer, limited to 1.5 Mev gamma rays, detected 0.43±0.02 Mev radiation when Li^6 was bombarded with protons of energy 180 kev to 415 kev. Spectrometer efficiency was measured using beta-gamma coincidences and a Au^{198} source. The thick target yield was $(7\pm4)\times10^{-13}$ gammas per proton at 180 kev and $(170\pm35)\times10^{-13}$ at 415 kev. This gamma ray was interpreted as part of the cascade decay[1] of the broad, third excited state of Be^7 at about 6.4 Mev, since the spectrometer, when unlimited, detected gamma rays corresponding to transitions to the ground and 0.43 Mev state in Be^7. The ratio of the partial radiation width for the latter transition to the total radiation width was >0.01 by comparison of the intensity of 0.48 Mev radiation from Li^{7*} produced after a lengthy bombardment at 365 kev (none) with the amount of 0.43 Mev radiation produced during the bombardment. This limit, together with the known properties of the ground and first excited states of Be^7, requires the transitions to these states from the capture state to be of the same multipole type and order and the spin of the capture state to be $\frac{1}{2}$ or $\frac{3}{2}$.

† Supported in part by U. S. Atomic Energy Commission.
[1] Erdman, Warren, James, and Alexander, Bull. Am. Phys. Soc. **29**, No. 6, 23(A) (1954).

H2. Electron-Neutrino Angular Correlation in the Beta Decay of Neon-19. D. R. MAXSON, J. S. ALLEN, AND W. K. JENTSCHKE, *University of Illinois.*—The electron-neutrino angular correlation in the beta decay of Ne^{19} has been measured by observing the energy spectrum of F^{19} recoil ions. The constant λ in the angular correlation function $(1+\lambda v_e/c\cos\theta_{ev})$ was found to be $\lambda=-0.21\pm0.08$, indicating that the beta-decay interaction is of the form *STP* and not *VTP*. The observed angular correlation leads to the result $C_S^2|\int\mathbf{1}|^2/C_T^2|\int\boldsymbol{\sigma}|^2=0.69\pm0.17$, which is consistent with $C_S^2\cong C_T^2$ if the nuclear configuration is $(d_{5/2})_f^3$, but not if the configuration is $(s_{\frac{1}{2}})_f^3$. Most of the F^{19} recoils carried one unit of negative charge, but singly charged positive ions were also detected. The coincidence rate due to positive ions was about 10 percent of that due to negative ions. No doubly charged recoils were observed.

H3. Decay of $_{22}Ti^{51}$ (5.8 min). S. B. BURSON, W. C. JORDAN, AND J. M. LEBLANC, *Argonne National Laboratory.*—The radiations from Ti^{51} have been studied with a scintillation coincidence spectrometer. Gamma rays of 0.32, 0.61, and 0.92 Mev are resolved. Their intensities are estimated to be in the ratio 100:1:5, respectively. The 0.32 and 0.61-Mev gamma rays are in coincidence. Two beta-ray components are resolved; one of approximately 2.4 Mev is in coincidence with the 0.32-Mev gamma ray, and one of 1.8 Mev is in coincidence with the 0.92-Mev radiation. No indication of a beta transition to the ground state of V^{51} is observed. The total disintegration energy is concluded to be 2.7±0.2 Mev. This value is consistent with energy systematics of odd mass beta-ray emitters.

H4. Anisotropic Gamma Radiation from Aligned Nd^{147} Nuclei.* E. AMBLER AND R. P. HUDSON, *National Bureau of Standards,* AND G. M. TEMMER, *Department of Terrestrial Magnetism, Carnegie Institution of Washington.*—We have aligned Nd^{147} nuclei using the same low-temperature method as that already reported for Ce^{141} nuclei.[1] Alignment again occurs in a plane perpendicular to the axis of symmetry

(z axis) in the paramagnetic salt used to cool the nuclei. Separate observations were made on the angular distributions of the 530-kev and 92-kev gamma radiations. For the 530-kev gamma ray, an anisotropy $\epsilon = -0.29$ was observed at the lowest temperature reached ($\simeq 0.003$°K). Assuming spin $9/2^-$ for Nd^{147} we conclude that the gamma transition is $E2$, and that the spins involved in the decay chain are $9/2^- \rightarrow 9/2^+ \rightarrow 5/2^+$. No significant anisotropy was observed for the 92-kev gamma ray and it is concluded that this transition is a mixture of $M1$ and $E2$ radiation. The spins involved in the decay chain are $9/2^- \rightarrow 7/2^+ \rightarrow 5/2^+$. From the temperature dependence of the anisotropy we deduce a value 0.22 ± 0.05 nm for the magnetic moment of Nd^{147}. This rather small value (together with our value of 0.16 ± 0.06 nm for Ce^{141}) may not be meaningful because of possible internal magnetic field effects. This, however, does not affect our other conclusions.

* Assisted by the Office of Naval Research.
[1] Ambler, Hudson, and Temmer, Phys. Rev. **95**, 625 (1954); also Phys. Rev. (to be published).

H5. Inner Bremsstrahlung from A^{37}.† TORSTEN LINDQVIST AND C. S. WU, *Columbia University.*—Recent investigations[1,2] on the distribution of inner bremsstrahlung from electron capture processes of Fe^{55} and Cs^{131} have shown that the theoretical predictions[3,4] which take account only of the K-electron capture are not adequate in interpreting the low-energy region of the distribution. We have recently reinvestigated the inner bremsstrahlung from A^{37} with particular emphasis on the low-energy region. The NaI crystal used in the scintillation spectrometer is permanently canned in a container with a window of thin Al foil (1 mil). The observed spectrum is corrected for the NaI crystal detection efficiency, geometrical factor, photopeak to Compton-electron ratio, and resolution of the system. It is concluded that the intensity of the low-energy photons is much more than that which can be accounted for by Morrison and Schiff's treatment. A better agreement can be obtained if one considers the p-electron capture and takes the Coulomb effect into the treatment as is shown by Glauber and Martin.[5]

† This work was supported by the U. S. Atomic Energy Commission.
[1] L. Madansky and F. Rasetti, Phys. Rev. **94**, 407 (1954).
[2] B. Saraf, Phys. Rev. **94**, 642 (1954).
[3] P. Morrison and L. I. Schiff, Phys. Rev. **58**, 24 (1940).
[4] J. M. Jauch, Oak Ridge National Laboratory, ORNL-1102, 1951 (unpublished).
[5] R. J. Glauber and P. C. Martin, Phys. Rev. **95**, 572 (1954).

H6. Disintegration of Niobium-91 and -92. R. W. HAYWARD, D. D. HOPPES, AND H. ERNST, *National Bureau of Standards.*—The radiations from the 60-day Nb^{91} and the 10-day Nb^{92} isotopes have been investigated using magnetic lens, scintillation-pulse height, and coincidence counting techniques. Isotopic identification has been made from threshold energies of the following reactions: $Mo(d,\alpha)Nb$, $Nb(\gamma,xn)Nb$, $Zr(d,xn)Nb$, and $Y(\alpha,xn)Nb$. In Nb^{91} two gamma rays were observed, a 1.21-Mev gamma ray 6.1 times the intensity of the unconverted portion of a strongly converted 0.104-Mev isomeric transition of $M4$ multipolarity. The 1.21-Mev gamma ray is in coincidence with Zr x-rays, indicating appreciable K capture. This gamma ray is the same as that occurring in the disintegration of Y^{91}. In Nb^{92} three gamma rays were observed with the following energies and relative intensities per disintegration: 0.930 Mev (0.98), 0.900 Mev (0.01), and 1.83 Mev (0.02). The first two gamma rays are in coincidence with each other and all are in coincidence with Zr x-rays. Decay schemes based on the experimental results will be proposed.

H7. Electromagnetic Radiations of Cs^{132}.† BEROL L. ROBINSON AND RICHARD W. FINK, *University of Arkansas.*—A sample of Cs^{132} was prepared by bombarding "Specpure" CsCl with 80-Mev protons in the University of Rochester 130-inch cyclotron[1] and by subsequent radiochemical purification. The half-life was 6.2 ± 0.2 days by gamma counting. Scintillation spectrometer studies showed gamma rays at 669 ± 3 kev, 1100 ± 40 kev, and 1265 ± 20 kev, the ratio of the intensities being $1000 : (7 \pm 2) : (8 \pm 2)$, respectively. By means of an x-ray-gamma coincidence experiment, the branching ratio to the 669-kev state was found to be 0.9 ± 0.2. Major sources of error in this measurement arise from uncertainties in the absolute calibration of a Cs^{137} standard, and in the decay constants of Cs^{132} and Cs^{131} which were present as a contaminant. From the branching ratio we deduce that electron capture to the ground state of Xe^{132} is forbidden and that Cs^{132} has $I \geq 2$, in agreement with shell model predictions. Gamma-gamma coincidences were observed, but the 1265-kev gamma ray is not coincident with the 669-kev transition. We observed a gamma ray at 365 ± 6 kev, which decayed with a half-life of about 30 hours, and which is attributed to Cs^{129}.

† Supported in part by the U. S. Atomic Energy Commission.
[1] The bombardment was performed through the courtesy of Professor E. O. Wiig and the Rochester cyclotron crew.

H8. Radioactive Tl^{204} and Bi^{207}. L. S. CHENG, VIRGINIA C. RIDOLFO, M. L. POOL, AND D. N. KUNDU, *Ohio State University.*—An activity from a deuteron bombardment of thallium has been recorded for ten years with an ionization chamber. The half-life is $2.5 + 0.03$ years. The activity is chemically thallium, and the beta spectrum was shown, by absorption measurements made with a Geiger counter and nucleometer, to be identical with that of the 4.0-year Tl^{204}. An activity of four years could not be found. From a lead bombardment an activity was found which showed a half-life of 8.0 ± 0.6 years based upon observations for eleven years. Chemically the activity is bismuth and the electromagnetic spectrum in a scintillation spectrometer is identical with that of the 50-year Bi^{207}. The five neighboring activities in Tl, Pb, and Bi were identified, however, essentially as recorded in the literature, by chemical separations, characteristic radiations, and half-lives.

H9. Extranuclear Effects on the Directional Correlation of the Ta^{181} Gamma Rays.* H. PAUL AND R. M. STEFFEN, *Purdue University.*—The directional correlations of the Ta^{181} gamma rays have been measured before by McGowan,[1] who found the anisotropies to be strongly influenced by the source composition. To investigate the role of the time-dependent quadrupole interaction in the 480-kev excited state of Ta^{181}, the correlation of the 132-kev–480-kev cascade displayed by solutions of Hf^{181} of different viscosities was measured using a coincidence scintillation spectrometer. The viscosity was changed by adding different amounts of glycerine to the solutions and by varying the temperature. In contradistinction to similar experiments[2] with In^{111}, Hf^{181} in different solvents with equal viscosities shows strongly different directional correlations. This might be traced to the formation of complex Hf ions in some of the cases. A spin assignment different from McGowan's is suggested which agrees fairly well with the angular correlation results,[1] but is consistent also with expected gamma lifetimes and recent Coulomb-excitation data.

* Supported by the U. S. Atomic Energy Commission.
[1] F. K. McGowan, Phys. Rev. **95**, 471 (1954).
[2] P. B. Hemmig and R. M. Steffen, Phys. Rev. **92**, 823 (1954).

H10. Gamma-Gamma Correlation of Pb_{2}^{04m}. SOL RABOY AND VICTOR E. KROHN, *Argonne National Laboratory.*—The angular correlations of the 913–374-kev and 913–898-kev gamma-ray pairs of Pb^{204m} have been measured in liquid media (deuteron-irradiated thallium foils dissolved in HNO_3 and H_2SO_4). The anisotropy $([W(180°)/W(90°)]-1)$ of the delayed coincidences is 0.34 ± 0.02 for the 913–374-kev cascade and 0.44 ± 0.02 for the 913–898-kev cascade. The anisotropy as a function of the delay between the gamma rays was investigated and no attenuation was observed as the delay was increased from 0.185 to 0.550 microsecond. A ten percent

attenuation of the anisotropy during this time would be consistent with the data, but the aforementioned errors do not include an allowance for possible attenuation. Solid angle corrections of eight percent have been made with the assumption that the $P_4(\cos\theta)$ and higher terms can be neglected for this purpose.

H11. Alpha-Gamma Directional Correlation in Th^{228}. T. B. NOVEY, *Argonne National Laboratory.*—Measurements of the alpha-gamma directional correlation in the even-even alpha particle emitters have indicated[1,2] the presence of an attenuation of the anisotropy expected for the 0–2–0 spin sequence. It has been suggested[3] that this effect is due to the presence of electric quadrupole interactions in the crystalline sources. Recent work on Am^{241} has shown[4] that by the use of liquid film sources the quadrupole effect may be greatly attenuated; however, the expected correlation for this type of decay is not adequately provided by theory at present. Results of measurements with liquid film sources to Th^{228} will be presented showing the extent of the effect of the crystalline field interaction in a case where the unique directional correlation function $\sin 2\theta$ is expected.

[1] Beling, Feld, and Halpern, Phys. Rev. **84**, 155 (1951).
[2] G. M. Temmer and J. M. Wyckoff, Phys. Rev. **92**, 913 (1953).
[3] A. Abragam and R. V. Pound, Phys. Rev. **89**, 1306 (1953).
[4] T. B. Novey, Phys. Rev. (to be published).

H12. Angular Correlation of Photons from Positron Annihilstion in Light Metals. A. T. STEWART* AND R. E. GREEN,† *Dalhousie University.*—The angular correlation of gamma rays from positron annihilation in the light metals Li, Be, Na, Mg, Al, K, and Ca, has been measured. Two flat NaI scintillation crystals were placed about 5 m apart, with a source of annihilation radiation midway between them. The coincident counting rate was observed as a function of the angle defined by the position of the source and two counters. The half-width of the measured angular correlation curve is directly related to the average momentum of the center of mass of the annihilating pair. A measure of the momentum may be given by defining an effective Fermi energy in terms of the following assumptions: (1) the positrons are thermalized before annihilation; (2) they annihilate only with electrons of a free electron gas; and (3) the momentum of the annihilating electron is carried away by the two photons. The Fermi energies so determined are: Li, 4.6 ± 0.5; Be, 13.6 ± 0.9; Na, 3.3 ± 0.4; Mg, 7.4 ± 0.5; Al, 11.1 ± 0.9; K, 2.1 ± 0.3; and Ca, 4.8 ± 0.4 electron volts. It is interesting to note that these results are in good agreement with values calculated from the free electron theory.

* Member of the staff of Atomic Energy of Canada Limited, on temporary appointment to Dalhousie University during the academic term 1953–54.
† Now at McGill University, Montreal, Quebec.

FRIDAY AFTERNOON AT 2:00

Eckhart 133

(J. H. WILLIAMS presiding)

Apparatus of Nuclear Physics; Other Nuclear Topics

I1. Magnetic Analyzer for Nuclear Reactions. T. D. HANSCOME AND D. K. WILLETT, *Naval Research Laboratory.*—A 60-degree magnetic spectrograph has been constructed for application to Q measurements using the NRL 2-Mev Van de Graaff. The central radius of curvature is 32.14 cm. Six 1×3 inch nuclear track emulsions are arranged on tangents along the focus curve. The range of radii accommodated is approximately 30 to 40 cm. The magnetic field is regulated to better than one part in 50 000 by use of the nuclear magnetic resonance of the proton. The energy dispersion is 0.13 percent per mm at the center of the camera. The position of a monoenergetic group can be determined to ±0.2 mm. For a target of negligible thickness and 0.02-in. width, the resolution is 1000. The polonium alpha line is 7 kev wide, giving a practical resolution for thin targets of 750. The resolution and stability of the Van de Graaff permitted the use of 0.010-in. slits on the incident beam. The calibration is very nearly linear in the momentum. Normal oxygen targets (NiO) were bombarded with deuterons at 1.61 Mev. The proton groups were observed at the expected points on the plates. The width of the $C^{12}(d,p)C^{13}$ group (5.2 kev) from carbon contamination confirms that the line width for the $O^{16}(d,p)O^{17}$ groups is due to target thickness.

I2. Amplitude and Frequency Stabilized Adjustable High-Frequency Oscillator.* R. C. MOBLEY AND B. R. ALBRITTON, JR., *Louisiana State University.*—During development of the deflection system for an "Ion Buncher,"[1] need was found for a highly amplitude- and frequency-stable rf oscillator tunable in 100 kc/sec steps from 5.0 to 9.5 Mc/sec. This need has been met through development of a circuit which automatically maintains a free-running amplitude-controlled 5.0 to 9.5 Mc/sec oscillator in phase lock with any desired harmonic, between the 50th, and 95th, of a fixed-frequency 100-kc/sec Mecham Bridge crystal oscillator. To accomplish this the 100-kc/sec sine wave from the crystal oscillator is amplified, clipped, and differentiated to produce pulses 20 mμsec long. These pulses are then mixed in a 6BN6 gated beam tube with the sine wave from the free-running oscillator. The resultant phase-sensitive signal, after further amplification at 500 kc/sec and rectification, biases a reactance tube across the tank circuit of the free-running oscillator so as to maintain a fixed phase relationship between the two oscillators.

* This work was supported in part by the University Council of Research, Lousiana State University.
[1] R. C. Mobley, Phys. Rev. **88**, 360 (1952).

I3. A Determination of the Bremsstrahlung Spectrum Produced by 18-Mev Electrons.* R. L. STEARNS, J. W. ROBSON,† AND E. C. GREGG, *Case Institute of Technology.*—A relative measurement of the energy spectrum of the Case betatron has been obtained by performing a magnetic analysis of Compton electrons ejected from a 38-mil beryllium scatterer. The electrons in the forward direction pass through a 60° magnet and are detected by means of a plastic scintillator (Plastifluor B) and a Du Mont 6292 photomultiplier. The raw data were corrected for multiple-scattering effects and converted through the known Compton cross section to a photon distribution.[1] The spectrum compared favorably with that calculated by Schiff[2] assuming a 20-mil molybdenum target. The agreement was within the statistical accuracy of the experiment (about ±5 percent) except at the lowest energy (5.65 Mev), at which

point the discrepancy is attributed to the failure of the multiple-scattering calculations.

* This work supported by the U. S. Atomic Energy Commission.
† Now at the University of Arizona, Tuscon, Arizona.
[1] See following abstract.
[2] L. Schiff, Phys. Rev. **70**, 87 (1946).

I4. Emergent Electron Distribution Resulting from Bremsstrahlung Incident on a Thin Scatterer.* J. W. ROBSON,† R. L. STEARNS, AND E. C. GREGG, *Case Institute of Technology.*—In deducing the bremsstrahlung spectrum incident on a thin foil from the observed energy distribution of Compton electrons one must consider multiple scattering in the foil as well as the usual Compton cross section. The number of electrons reaching the detector when it is set to detect electrons of kinetic energy T is given by

$$n(T)=\int_{T-\Delta T/2}^{T+\Delta T/2} E(T')\left[\int NA(\psi,E_2)\frac{\partial\sigma}{\partial\psi}B(E_2)\frac{\partial\psi}{\partial T}dE_2\right]ZdT',$$

where $E(T')$ is the detector efficiency, N is a constant depending on the scatterer, $A(\psi,E_2)$ is the probability of an electron being detected, $\partial\sigma/\partial\psi$ is the Klein-Nishina cross section per unit electron angle, and $B(E_2)$ is the desired photon distribution. Also $A(\psi,E_2)=\int p(\theta,\theta_m)W(\theta,\psi)d\theta$, where $p(\theta,\theta_m)$ is the probability of an electron of kinetic energy T being multiply scattered through an angle θ; this probability was evaluated using the results of Bethe, Rose, and Smith. $W(\theta,\psi)$ is the probability of such an electron being detected.

* This work supported by the U. S. Atomic Energy Commission.
† Now at the University of Arizona, Tucson, Arizona.
[1] Bethe, Rose, and Smith, Proc. Am. Phil. Soc. **78**, 573 (1938).

I5. Coupling of Betatron and Phase Oscillations in a Synchrotron. E. A. CROSBIE AND M. HAMERMESH, *Argonne National Laboratory.*—The coupled equations for radial position, momentum, and phase oscillations in a synchrotron are treated by use of difference equations. The effect of a radial variation in the accelerating radio-frequency voltage is included in the treatment; any resultant damping of one type of oscillation is shown to be necessarily accompanied by equal antidamping of oscillations of the other type. A simple treatment of the adiabatic variation of parameters for systems of linear differential or difference equations is given.

I6. A Crystal Technique for Measuring Cyclotron Beam Energies. PHILIP YUSTER, SOL ROCKLIN, WARREN RAMLER, AND CHARLES DELBECQ, *Argonne National Laboratory.*—A lithium fluoride crystal, when irradiated with deuterons from a cyclotron, develops a yellow color; if the deuterons are stopped within the crystal there is a sharp demarcation in color between the irradiated and unirradiated portions. It has been found that the measurement of the depth of penetration of the color into lithium fluoride crystals can be used to determine accurately and rapidly the energy of deuterons in a cyclotron beam. A single exposure of a crystal to the deuteron beam can be used to determine not only the energy of the deuterons but also the angular orientation of the beam trajectories.

I7. A New Technique for Observing Cyclotron Phase Grouping.* STEWART D. BLOOM, *Brookhaven National Laboratory.*—The phase grouping of the beam on the Brookhaven 18-in. cyclotron has been observed to be of the order of 1–2 mμsec out of 54 mμsec (18.6 Mc), in agreement with theoretical prediction.[1] The measurement was accomplished by allowing the 1-ma, 2.6-Mev deflected proton beam to impinge upon an appropriate target, and then looking for coincidences between the resultant γ rays due to (p,γ) processes, and rf voltage "pips" occurring once per rf cycle. The rf-coincidence technique utilized the new Philips 6218 beam-deflection tube in fundamentally the same manner as originally proposed,[2] with the exception of the introduction of the γ-detection signal on the first focusing grid. In the present work resolution times of 0.5–1.0 mμsec were used, though better resolutions are achievable. The immediate intention is to apply this method to the general problem of inelastic neutron scattering using time-of-flight techniques. Also an investigation is being made of the possibilities of the method in observing the decay of metastable states.

* Research carried out under the auspices of U. S. Atomic Energy Commission.
[1] B. L. Cohen, Rev. Sci. Instr. **24**, 589 (1953).
[2] Bruysten, Groendijk, and Mantz, Communication News **XIII**, No. 1, 13 (1953).

I8. The Synchro-Microtron. H. F. KAISER, *Naval Research Laboratory.*—Among several methods proposed[1] for increasing the maximum particle energy of the microtron is considered the use of an auxillary magnetic field over the region of the final microtron orbit so that further acceleration of electrons in this orbit could proceed in a rising field as in a synchrotron. Here an extension of this idea will be discussed in which the field will rise in a stepwise or quasi-stepwise way. The field system is regarded as a transmission line carrying a current wave at nearly particle speed. In one form it is operated as two semicircular parts for each of which the "delay time" is nearly the orbital period. The effect is a constant current during each period which rises stepwise in time. A similar effect is obtained with a circular line beginning at the resonator and terminating in its characteristic impedance. If field and energy increments satisfy $T_n=(2\pi/\mathrm{cc})[(E_n+\Delta E)/(H_n+\Delta H)]$, acceleration is possible to an energy limited by the field attainable. The system exhibits regions of phase stability, which, moreover, is preserved even when the average rate of field rise is slightly nonlinear.

[1] H. F. Kaiser, Phys. Rev. **95**, 667 (1954).

I9. A Theory of Cavity Ionization. L. V. SPENCER AND F. H. ATTIX, *National Bureau of Standards.*—Measurements by Attix and De La Vergne[1] of the cavity ionization produced by γ rays, as a function of the wall material, do not agree with the predictions of the Bragg-Gray theory, which neglects effects due to the travel of fast secondary electrons generated in inelastic collisions. These effects depend strongly on the difference between the atomic numbers of the gas and wall materials. We propose a new theory in which only collisions transferring energies less than a cut-off Δ are dissipative. The parameter Δ may be related to the cavity size. Calculations based on this theory agree well with the measurements of Attix and De La Vergne. They also indicate a variation in the ionization per gram of air as a function of cavity size which agrees with measurements by Gray.[2] According to these new considerations, measurements with extrapolation to zero cavity size have at best a questionable interpretation.

[1] F. H. Attix and L. De La Vergne (to be published).
[2] L. H. Gray, Proc. Roy. Soc. (London) **A156**, 578 (1936).

I10. Performance Characteristics of the BNL Research Electrostatic Accelerator.* C. M. TURNER, *Brookhaven National Laboratory.*—Preliminary tests have been carried out with accelerated hydrogen ion beams in the revised BNL research electrostatic accelerator following the incorporation of effective x-ray suppression at the anode end of the 8-foot-long acceleration tube.[1] A capillary arc type source with capillary probe is presently used. General performance specifications are as follows: (1) nominal rating, 3.5 Mev, 50 microampere analyzed proton beam, 25 mr/hr x-ray intensity beside tank; (2) maximum present rating, 4.0-Mev, 75-microampere proton beam, 150 mr/hr beside tank; (3) proton yield, 50–75 percent; (4) maximum power in the total ion beam (focusable

to a 3/32-in.-diameter spot), approximately 1 kilowatt; (5) voltage stability without regulation, 0.2 to 0.3 percent.

* Work performed under the auspicies of the U. S. Atomic Energy Commission.
[1] C. M. Turner, Phys. Rev. **95**, 599(A) (1954).

I11. The Effect of Temperature upon the Scintillation Efficiency of NaI(Tl). L. A. WEBB AND R. F. JOHNSON, *U. S. Naval Radiological Defense Laboratory.*—Studies have been made of the effect of temperature upon the scintillation efficiency of crystals of NaI(Tl) over the range of 5°C to 45°C. The samples used were 1-in.×1-in diameter crystals sealed in standard commercial packages with MgO reflecting surfaces. The samples were coupled to a 6292 photomultiplier tube by means of a special light pipe which permitted the change of temperature of the crystal package only, while the operating conditions of all other components remained constant. All temperatures were controlled by means of circulating oil. Crystal temperature *vs* the pulse height output of the Cs^{137} total absorption line as recorded by a gamma-ray scintillation spectrometer shows a coefficient of -0.12 ± 0.02 percent per centigrade degree. This value agrees quite well with that obtained by others.[1]

[1] "Round Table Discussion of Photomultiplier and Phosphors," Scintillation Counter Symposium, 1954; Nucleonics **12**, No. 3, 28 (1954).

I12. Double-Scattering Experiment with 96-Mev Protons.* KARL STRAUCH, *Harvard University.*—The external cyclotron beam (energy 96 Mev, spread 2 Mev) has been used to perform a double-scattering experiment. When both scatterers were carbon, it was possible to make sure that the majority of detected protons were elastically scattered in both targets. Although not as certain, the same fact is believed to be true with the other targets investigated. The first and second scatterings took place at average energies of about 87 Mev and 66 Mev, respectively. Measured values of $\epsilon = R-L/R+L$ are as follows:

Target 1	Target 2	θ_1	θ_2	ϵ
Cu	Cu	26°	18°	$4.3\pm1.7\%$
C	Cu	8.5°	18°	$0.3\pm1.8\%$
C	C	8.5°	18°	$1.7\pm2.0\%$
C	C	15°	15°	$3.0\pm1.6\%$†
C	C	20°	20°	$3.6\pm1.6\%$†
Be	Be	20°	20°	$3.1\pm1.8\%$†

These results will be discussed and compared with other experiments.

* This work was supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Correction for geometric inhomogeneity of first scattered beam has been applied.

I13. Elastic Scattering of 0.41 and 0.66 Mev Gamma Rays* by Tin and Lead. A. K. MANN, *University of Pennsylvania.*—Collimated beams of 0.41- and 0.66-Mev gamma rays were scattered from tin and lead targets and the absolute differential cross sections for elastic scattering measured at five angles between 15 and 75 degrees. The scattered radiation was detected with a NaI scintillation counter to select only the energy region of elastic scattering. At the smaller angles, the degraded radiation from Compton scattering was subtracted empirically by comparing the tin and lead scattering with that from an aluminum target containing the same number of electrons. At these energies the predominant mode of elastic scattering should be Rayleigh scattering from the tightly bound electrons. Within the experimental error of about 10 percent the measured differential cross sections for lead at both 0.41 and 0.66 Mev do not differ significantly from the calculation of Rayleigh scattering made by Franz,[1] using the Thomas-Fermi model. For tin at 0.66 Mev the measured values at large angles appear to be less than those given by Franz, but no such disagreement is evident at 0.41 Mev.

* Supported in part by the Air Research and Development Command.
[1] W. Franz, Z. Physik. **98**, 314 (1935).

FRIDAY AFTERNOON AT 2:00

Cobb 110

(J. M. JAUCH presiding)

Invited Papers

K1. The Photodisintegration of Deuterium. A. O. HANSON, *University of Illinois.* (30 min.)

K2. A Partial-Wave Analysis of the Experimental Photomeson Cross Sections and Its Interpretation. K. M. WATSON, *University of Wisconsin.* (30 min.)

Theoretical Nuclear Physics

K3. Coulomb Effects in the (d,p) Reaction.* R. W. HOCKNEY AND P. V. C. HOUGH, *University of Michigan.*—The Schrodinger equation for the motion of a neutron and a proton in the field of a nucleus is transformed by standard techniques to a differentio-integral equation for the motion of the proton when the neutron is bound in a particular harmonic oscillator state. The Coulomb force on the proton gives rise to a source term in Born approximation. As a slight justification for the Born approximation, the most important neutron impact parameters are found to be somewhat larger than the nuclear radius. For 7.8-Mev deuterons incident on O^{16} and leading to the 0.88-Mev, 2*s* state in O^{17}, the Coulomb amplitude in the forward direction is about one-third the Butler amplitude and interferes destructively, thereby reducing the theoretical cross section by almost a factor 3 and establishing reasonable agreement with experiment.[1] The nuclear radius required to fit the position of the first minimum in the experimental angular distribution is reduced from $\sim6\times10^{-13}$ cm to $\sim4\times10^{-13}$ cm, the formula $R=1.4\ A^{\frac{1}{3}}$ giving 3.5.

* Supported by the Michigan Memorial Phoenix Project and by the U. S. Atomic Energy Commission.
[1] W. J. Childs and W. C. Parkinson, private communication. Burge *et al.*, Proc. Roy. Soc. (London) **A210**, 534 (1952).

K4. Isotopic Spin Impurity in Light Nuclei. W. M. MACDONALD, *University of California, Berkeley.*—The validity of the total isotopic spin quantum number T^2, which exists under the assumption of "charge independent" nuclear forces of the form $\Sigma(a+b\boldsymbol{\tau}_i\cdot\boldsymbol{\tau}_j)$, is impaired only by the Coulomb potential. Charge independence must therefore be renounced unless the Coulomb potential can explain the isotopic spin impurity determined experimentally from violations of the isotopic spin selection rule on electric dipole transitions.[1] The impurity introduced by the Coulomb potential has been calculated, taking into account first the interaction of outside nucleons

among themselves and with the core of nucleons in closed shells. Secondly, we have calculated the effect on isotopic spin impurity of the interaction of nucleons in closed shells. This latter "core impurity," neglected in previous work[1] has been found to be larger by a factor of ten than that due to nucleons outside closed shells. The isotopic spin impurity of the normal states of nuclei with $A \leq 20$ has been found to vary in intensity (squared amplitude of higher isotopic spin states) from $\sim 3\times10^{-3}$ for He^4 to 2×10^{-2} for Ne^{20}. This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] L. A. Radicati, Proc. Phys. Soc. (London) **66A**, 139 (1953); **67A**, 39 (1953).

K5. Supermultiplet Structure and Spin Dependent Forces.* R. W. KING, *National Research Council.*—While Wigner's supermultiplet formalism provides the most natural theoretical explanation of the empirical difference between favored and unfavored β decay, it does not permit favored negatron decay for odd A nuclei with $A>3$. There is considerable experimental evidence from the decay of $T_z=\frac{3}{2}$ nuclei to excited states of $T_z=\frac{1}{2}$ nuclei that is contrary to such a restriction. An explanation of this group of favored negatron transitions is proposed on the basis of a deviation from the supermultiplet formalism due to spin dependent nuclear forces. An expression for the energy difference between the $T_z=\frac{3}{2}$, $S=\frac{1}{2}$ parent state and the $T_z=\frac{1}{2}$, $S=\frac{3}{2}$ daughter state belonging to the same supermultiplet contains at least two spin dependent terms opposite in sign to the Coulomb energy difference. Super allowed negatron decay is thus possible within supermultiplets of the $[4^k+3+2]$ or $[4^k+2+1]$ type for any A where the energy gained by these two spin dependent terms is greater than the coulomb energy difference between the parent and daughter state. Empirically such a condition seems to prevail for $A \lesssim 25$. Some needed experimental measurements will be discussed.

* Work supported by the U. S. Atomic Energy Commission.

K6. Molecular Excitation in Beta Decay. MURRAY CANTWELL,* *Washington University.*—A theoretical study has been made of the formation, following the beta decay of one of the nuclei of a tritium molecule, of the daughter helium-tritide molecule ion in the various rotational states associated with the first three vibrational levels of its ground electronic state. It is predicted that a sample of tritium will emit about 2×10^{13} photons per second per gram with a wave number of approximately 3100 cm^{-1} due to the radiative deexcitation of the first excited vibrational level of the ground electronic state of the daughter molecule ion. The effect of the type of beta-decay coupling on the distribution of the helium-tritide molecule ion over its excited vibrational states is less than one percent because of the relatively small beta electron velocity in tritium. In addition general curves have been constructed giving the probability that a diatomic molecule will remain bound after the beta decay of one of its nuclei as a function of the beta-energy release, of the internuclear potential well parameters, and of the number of stable vibrational levels in the electronic state of the daughter molecule.

* NSF fellow, assisted by joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

K7. The Importance of Parentage of Nuclear States for Nuclear Reaction Phenomena.* D. H. WILKINSON,† *Brookhaven National Laboratory* AND A. M. LANE, *AERE, Harwell, England.*—The concept of fractional parentage of nuclear states is briefly reviewed. It is pointed out that many dynamical properties of nuclear systems—transition rates and level widths—are directly controlled by products of the coefficients of fractional parentage for common parents—the "parentage overlap"—between initial and final states. Illustrations are given from a range of nuclear reactions including radiative transitions, high and low energy stripping, pickup, and photonuclear processes. It is particularly to be emphasized that, because of the occurrence of the coefficients of fractional parentage and certain (vector coupling) weighing factors in the expression for the transition rate, one may find reduced and radiative widths very considerably less than the "single particle" values even though the states concerned are wholly of an independent particle character.

* Work partially done at Brookhaven National Laboratory under the auspices of the U. S. Atomic Energy Commission.
† On leave from the Cavendish Laboratory.

K8. An Intermediate Coupling Model of Lithium-6. R. H. ADKINS AND J. G. BRENNAN, *The Catholic University of America.*—Horie and Yoshida[1] have obtained a wave function for the ground state of lithium-6 from a $(p)^2$ configuration. This has been done by imposing the requirements that the known magnetic moment and electric quadrupole moment be reproduced. This work has been re-examined and it is found that two wave functions from a $(p)^2$ configuration satisfy these requirements. One of these wave functions corresponds to that of Horie and Yoshida; the other differs considerably from it. An attempt has been made to make a selection between these two within the scope of an intermediate coupling model neglecting configuration interaction. The results are not conclusive, but there seems to be an indication that a modified Hall and Powell potential[2] which has the latter of these two wave functions as its lowest state gives a more satisfactory energy level structure for this nucleus.

[1] H. Horie and S. Yoshida, Progr. Theoret. Phys. **6**, 829 (1951).
[2] H. H. Hall and J. L. Powell, Phys. Rev. **90**, 912 (1953).

K9. Tensor Force Interaction Energies for Configurations Important in O^{18} and F^{18}.* D. R. BACH, C. R. LUBITZ, AND P. V. C. HOUGH, *University of Michigan.*—The two-nucleon jj configurations $d_{5/2}d_{5/2}$, $d_{5/2}d_{3/2}$, $d_{3/2}d_{3/2}$, $d_{5/2}s_{1/2}$, $d_{3/2}s_{1/2}$, $s_{1/2}s_{1/2}$ are probably responsible[1] for all the low-lying even parity states in the polyad of mass 18. Matrix elements of the tensor force have been calculated for these configurations in terms of the radial integrals I_l of the harmonic oscillator wave functions.[2] Energies of states of isobaric spin $T=1$ have been obtained both by the Slater method and using the tensor algebra of Racah[2]; those of $T=0$ have been calculated by the second method only. The dependence of the level scheme in O^{18} and F^{18} on the relative strength of central and tensor forces, and on the two ranges and shapes is under investigation.

* Supported in part by the U. S. Atomic Energy Commission.
[1] M. G. Redlich, Phys. Rev. **95**, 448 (1954).
[2] I. Talmi, Phys. Rev. **89**, 1065 (1953).

K10. Excited States of C^{12} and O^{16}.* L. I. SCHIFF, *Stanford University.*—The matrix element for the electric monopole transition in O^{16} computed from the pair emission lifetime[1] has roughly the same magnitude as the matrix element between the ground and 7.68-Mev states in C^{12} estimated from inelastic electron scattering,[2] assuming that the latter is also electric monopole.[3] Both matrix elements are much smaller than would be expected on the basis of an alpha particle model, an elastic fluid model, or a $1S\rightarrow2S$ transition of a single proton. It seems possible that this can be explained on the independent particle model (IPM) if two particles change their states. The transition is then forbidden if the IPM is taken literally, but becomes allowed if some interaction between particles is admitted in addition to that which is included on the average in the IPM. An estimate of the magnitude of this residual interparticle interaction that is required to explain the matrix elements will be presented.

* Supported in part by the Office of Scientific Research, Air Research and Development Command.
[1] Devons, Goldring, and Lindsey, Proc. Phys. Soc. (London) **A67**, 134 (1954).
[2] R. Hofstadter and J. H. Fregeau, private communication.
[3] G. Harries, Proc. Phys. Soc. (London) **A67**, 153 (1954).

FRIDAY AFTERNOON AT 2:00

Mandel Hall

(S. K. ALLISON presiding)

Invited Papers

L1. The Temperature of the Primitive Earth. H. C. UREY, *University of Chicago.* (30 min.)

L2. Review of the MURA High-Energy Accelerator Programme. D. W. KERST, *University of Illinois.* (30 min.)

SATURDAY MORNING AT 9:30

Oriental 104

(F. F. RIEKE presiding)

Nonmetallic Solids, Mostly Crystals

P1. Electrical Conduction in Plastics. RAYMOND J. MUNICK, *Argonne National Laboratory.*—Electric current from specimens of Lucite, fluorothene, polystyrene, polyethylene, and Teflon was found to consist of two parts. One part decreases with time elapsed from initial voltage application as t^{-n} with n around 1,[1] depends on voltage changes, and changes little with temperature from 25 to 49°C although it attains a maximum in magnitude for Lucite and fluorothene around −30 and −55°C, respectively. The other part appears almost steady, depends on voltage, and increases exponentially as the reciprocal absolute temperature[2] from 25 to 49°C with activation energies around 1 electron volt. The almost steady part shows a slight decrease with time, which is more rapid at higher temperatures, an effect which others have observed for crystalline insulators.[3] The conductivities indicated by the steady current are less than 10^{-19} mhos cm^{-1}.

[1] Warner, Muller, and Nordlin, J. Appl. Phys. **25**, 131 (1954); P. Ehrlich, J. Appl. Phys. **25**, 1056 (1954).
[2] N. W. Ramsey, Nature **172**, 214 (1953); Fowler and Farmer, Nature **171**, 1020 (1953); **173**, 317 (1954); **174**, 136 (1954).
[3] A. J. Joffe, *The Physics of Crystals* (McGraw-Hill Book Company, Inc., New York, 1928), Lecture VIII.

P2. Mechanism of High-Speed-Waterdrop Erosion of Methyl Methacrylate Plastic. OLIVE G. ENGEL, *National Bureau of Standards.*—The erosion that waterdrops cause when they strike solid surfaces at very high velocities has become important because of the damage produced when high-speed aircraft fly through rain. This erosion is essentially the same as that which occurs in steam turbines because of the waterdrops present in wet steam. The process has been studied for the past twenty-five years, but no clear understanding of the complete damage mechanism (or mechanisms) has emerged. The damage that results from these high-speed liquid-to-solid collisions is a function both of the impact properties of the waterdrop and of the properties of the material against which impingement occurs. Under impact conditions the waterdrop is essentially hard, but unlike a sphere of hard material it retains its liquid property of flow. A parallel study of the damage produced on methyl methacrylate plastic by the impingement of steel spheres and deforming lead pellets has contributed information in regard to the mechanism of the high-speed-waterdrop erosion of this plastic. Results of the parallel study will be described. The mechanism can be extrapolated with safety only to other brittle materials of low tensile strength the other characteristic properties of which are similar to those of methyl methacrylate plastic.

P3. Generation of Electron Traps by Plastic Flow. WERNER KÄNZIG AND MASAYASU UETA, *University of Illinois.*—Vacancy clusters generated by moving dislocations act as effective electron traps, and change the photographic properties of the alkali halides considerably. This has been investigated, using additively colored KCl and electrolytically colored NaCl. Electrons were released from the F centers by irradiation of F light. In a plastically deformed crystal these electrons are immediately captured by vacancy clusters and have not much chance to return to a negative ion vacancy. Therefore, the F band bleaches much faster than in the case of undeformed crystals. Measurements of the bleaching rates permit an estimation of the concentration of traps generated by plastic flow. About 10^{17} traps per cm^3 are formed by a plastic strain of 10 percent. The filled traps give rise to a very broad absorption band, centered in the near infrared. Photochemical processes, such as the formation of F', R, and M centers by irradiation of F light, are strongly affected by the presence of these traps. In additively colored KCl these centers cannot be formed after sufficient plastic deformation.

P4. The Thermal Formation of Colloids from F Centers in KCl Crystals. H. PAGNIA AND F. STÖCKMAN,* *Institute of Technology, Darmstadt, Germany* (introduced by K. LARK-HOROVITZ).—The thermal formation of colloids from F centers has been investigated in KCl crystals. Additively colored crystals have been tempered at temperatures between 250° and 400°C and the absorption spectra have been measured at intervals of some minutes. Results: the colloid band does not grow directly from the F band but appears only after some intermediate steps from which two agree with the M and R band. After tempering for a long time an equilibrium concentration of colloids is established which equals the difference of the excess potassium concentration and the equilibrium concentration of F centers at the temperature of tempering. The absorption band of the colloid shifts to longer wavelengths after tempering at higher temperatures, but its position does not depend upon the concentration of the colloids. According to the theory of M. Savastianova[1] this means that the colloids become larger if they grow at higher temperatures and that their size only depends upon this temperature.

* Now at Purdue University, Lafayette, Indiana.
[1] M. Savastianova, Z. Physik **64**, 262 (1930).

P5. Optical and Electrical Properties of Lithium Fluoride X-Rayed at Liquid Nitrogen Temperature. C. J. DELBECQ, P. PRINGSHEIM, AND P. H. YUSTER, *Argonne National Laboratory.*—When a lithium fluoride crystal is irradiated with x-rays at −190°C, absorption bands are formed at 242 mμ (*F* band) and at 340 mμ. It has been found previously that upon slow warming, such a crystal shows a large luminescence glow peak at about −133°C;[1] in the present investigation it has been found that the 340 mμ band almost completely disappears and the *F* band decreases appreciably between −170 and −120°C with a maximum rate of disappearance in both cases at about −134°C. When a lithium fluoride crystal, after irradiation at −190°C, is placed in an electric field and warmed slowly, the electrical conductivity of the crystal is observed to pass through a large maximum at about −130°C. This electrical conductivity is interpreted as being due to the migration of positive holes after being thermally released from their traps (*V* centers); the luminescence occurs when the positive holes are annihilated at electron excess centers, in this case the 340 centers and *F* centers. Experiments will be described which support this interpretation of the origin of luminescence and electrical conductivity.

[1] J. A. Ghormley and H. A. Levy, J. Phys. Chem. **56**, 548 (1952).

P6. Photoelastic Observation of the Expansion of Alkali Halides on Irradiation. W. PRIMAK, P. H. YUSTER, AND C. J. DELBECQ, *Argonne National Laboratory.*—Alkali halides crystals subjected to a nonuniform irradiation by x-rays or high-energy deuterons were found to become anomalously birefringent. The effect is shown to have been due to the photoelastic birefringence accompanying a nonuniform dilatation. The phenomenon was studied in detail in lithium fluoride. The dilatation due to irradiation is calculated from the measured birefringence with the aid of elasticity theory and is found to be about $2(10^{-4})$ at the end of the range after a bombardment of about 10^{13} d/cm². From a comparison of the absorption with the absorption of other crystals which had been carefully studied, the color center concentration is found to be about $2(10^{19})$/cm³. Thus the dilatation is about equal to the volume of vacancies associated with the color centers. Since an intrinsic property of the body of material has been studied, the effect cannot be attributed to a surface alteration, a criticism which has been leveled [F. Seitz, Revs. Modern Phys. **26**, 74 (1954)] against other determinations of density changes accompanying color center formation.

P7. Elastic Constants and Specific Heat of KCl at Elevated Temperatures.* F. D. ENCK† AND C. B. COOPER, *University of Maryland.*—Measurements of the adiabatic elastic constants of KCl have been made in the region 300° to the melting point (1043°K) by a dynamical method developed by Balamuth. Recently determined values of C_p have been used to obtain the isothermal values of the compressibility. The behavior of the elastic constants and the compressibility are compared with the theoretical predictions of Born and Furth and reasonable agreement is obtained. Values of C_v have been obtained, using values for the coefficient of linear expansion (α_l) measured by Eucken and Dannohl, and they would indicate that there is a drop in C_v above 700°K, but that this drop is considerably less than that found by Eucken in the case of NaCl. There is strong evidence that Eucken's values of α_l are systematically high at temperatures above 700°K; in fact, if the high temperature values of α_l are discarded in favor of an extrapolation from low temperature results, the Dulong-Petit law is valid up to the melting point.

* Supported by the Office of Naval Research.
† Now at Franklin and Marshall College.

P8. Thermal Ionization of Interstitials in Cubic Zinc Sulfide. H. D. VASILEFF, *Sylvania Electric Products Inc.*—The theory[1] of thermal ionization of impurities in polar crystals is applied to interstitials in cubic zinc sulfide. The interaction energy of the trapped electron with the optical vibrational modes is included in the electronic wave equation and the normal coordinate dependence of the electronic wave function and energy is determined through Simpson's[2] method. This leads to an evaluation of the displacement constant c and the configurational constant S occurring in the theory. The numerical evaluation of the frequency factor indicates that it has the form $s(E,T)$ at moderately high temperatures T but depends only on the trap depth E at low temperatures. For interstitials in cubic ZnS, $E=0.61$ ev, $S=1.2$, $s(E,320°\text{K})=10^{8.6}$ sec^{-1}, as deduced from an effective ionic charge of $e^*=0.5e$ for the lattice. These results are in reasonable agreement with experiment.

[1] H. D. Vasileff, Phys. Rev. **95**, 618 (1954).
[2] J. H. Simpson, Proc. Roy. Soc. (London) **A197**, 269 (1949).

P9. Photoconductivity and Photodesorption in Zinc Oxide.* DAVID B. MEDVED,† *University of Pennsylvania.*—Conductivity and photoconductivity processes in zinc oxide have been studied as functions of light intensity, pressure, and temperature. Most of the experiments were performed on very thin samples of sintered zinc oxide. The results are in agreement with the theory of chemisorption and conductivity developed by Miller,[1] Morrison,[2] and Melnick.[3] These experiments show that: (1) the rise of the photoconductivity in thin samples reaches saturation in several minutes or seconds (dependent on incident intensity) instead of increasing indefinitely. (2) The rates of rise and decay show that the kinetics involve an expression of the Elovich form $-(dn/dt)=ae^{bn}$. (3) The variation of the saturation values with intensity follows the logarithmic law developed by Melnick from considerations of the Elovich equation for the rate of chemical adsorption. (4) Measurements of pressure as a function of time in the range of 10^{-6} mm of Hg indicate that the incident light causes a photodesorption of the gas from the surface concomitant with the photoconductivity.

* Supported in part by contract with U.S.A.F.
† Now at Convair, San Diego, California.
[1] P. H. Miller and S. R. Morrison, Tech. Rep. No. 5, N6-onr-24914, August 6, 1952.
[2] S. R. Morrison, Tech. Rep. No. 4, N6-onr-24914.
[3] D. A. Melnick, Bull. Am. Phys. Soc. **29**, No. 3, 40, Paper X5 (March 18, 1954).

P10. Photoconductivity of Pyrolytic Layers of Boron.* C. H. HAYN AND VINCENT P. JACOBSMEYER, *Saint Louis University.*—Layers of elementary boron were deposited on tantalum ribbons at 807°C, 1060°C, 1260°C, 1377°C, and 1500°C by the pyrolysis of diborane gas. The activation energy as a function of deposition temperature was investigated by means of photoconductive measurements. For these studies evacuated Pyrex tubes, provided with quartz windows, were used. The boron sample was centered in the tube. Contact was made to the boron surface by two tungsten probes under pressure. Radiation from a G.E. tungsten projection lamp passed through a monochromator was the source of illumination. The activation energy was determined from the wavelength corresponding to half-maximum on the normalized photosensitivity curve. The following results were obtained for the five samples of boron: 0.75 ev for the 807°C sample, 1.66 ev for the 1060°C sample, 1.28 ev for the 1260°C sample, 0.81 ev for the 1377°C sample and 1.50 ev for the 1500°C sample. Comparing these results with data obtained from photoemission studies, it is found that the two samples having the highest activation energies are those which have the larger work functions. X-ray studies showed sharp diffraction lines for the 1060°C and 1500°C samples, while the pattern for the region around 1200°C was very diffuse.

* Supported by the National Science Foundation.

P11. Photoconductivity in Para-Terphenyl Single Crystals.* G. J. GOLDSMITH AND D. E. HILL, *Purdue University.*—The photoconductivity of terphenyl single crystals was investigated. One observes a strong absorption edge at 3400 A with a structureless band extending to the limit of observation, 2000 A. Photoconductivity was found to be present within this absorption band with a threshold corresponding to that of the absorption edge. Photocurrents up to about two orders of magnitude greater than the dark current are observed with the light sources available. The photocurrent is proportional to the light intensity. A sample illuminated perpendicularly to the field shows saturation of photocurrent. Illumination parallel to the field does not produce photocurrent saturation. The current increased far more rapidly when the positive electrode was illuminated than when the illuminated electrode was negative: predominant hole conduction. The photoconductivity increases more slowly with temperature than does the dark conductivity (see preceding abstract) giving an activation energy of the order of 0.2 ev.

* This work supported in part by a Motorola Research grant.

P12. Dark Conduction in Para-Terphenyl Single Crystals.* D. E. HILL AND G. J. GOLDSMITH, *Purdue University.*—Single crystals of para-terphenyl were prepared by growth in vacuum from the melt. Samples free from visible imperfections were selected and silver paste electrodes applied to the ends perpendicular to the cleavage faces. The samples were mounted in a specially designed chamber provided with a vacuum jacket and facilities for controlling the temperature. The conductivity as a function of temperature was measured using a vibrating reed electrometer as the detection device. It was found that the conductivity σ varied exponentially with reciprocal temperature with an activation energy $\epsilon = 1.2$ ev assuming intrinsic semiconduction.

$$(\sigma = \sigma_0 e^{-\epsilon/2kT}).$$

The field dependence of the current was linear up to fields of about 1000 v/cm and increased at higher fields. The resistivity at low fields at room temperature is 10^{14} ohm-cm. A waiting period of about two hours after application of the field was necessary to reach steady-state currents at room temperature. These results are consistent with those found by others for similar organic compounds containing conjugated bonding.

* This work supported in part by a Motorola Research grant.

[1] See, e.g., Eley, Parfitt, Perry, and Taysum, Trans. Faraday Soc. **49**, 79 (1953).

P13. Time-Average Light Output from Electroluminescent Phosphors. S. NUDELMAN* AND F. MATOSSI, *U. S. Naval Ordnance Laboratory.*—The time-average light output from cubic and hexagonal ZnS:Cu and Zn(S,Se):Cu electroluminescent phosphors has been investigated as a function of field strength, frequency, and time using sinusoidal and square wave field shapes. All observations were made with appropriate filters to determine the field influence on the green and blue emission bands independently. In general, the time-average light output in both bands grows with frequency up to 20 000 cps, the limit of our measurements. However, a phosphor with a slow natural decay of the green band shows a plateau-like region between 1000 to 4000 cps for the green light output. The field strength dependence follows a power law, with exponents ranging from 4 to 8. At low frequencies, square waves produce a greater light output than sine waves of the same peak to peak voltage. Fatigue measurements at 5000 cps indicated that the light output dropped from 25 to 75 percent of its starting value within a 24 hour period. The light output decreased according to a power law over most of this time.

* Also at the University of Maryland.

P14. Electroluminescence Excited with Short Field Pulses. F. MATOSSI AND S. NUDELMAN,* *U. S. Naval Ordnance Laboratory.*—Repetitious field pulses with pulse times from 2500 to 40 microseconds duration were applied to several electroluminescent phosphors. The slopes of the decay curves for both the green and blue luminescence bands become steeper as the pulse duration decreases. The heights of the luminescence peaks excited at the leading and the trailing edges of the pulses also depend on the pulse duration. In this respect, bands with fast and with slow natural decay behave differently. The results are interpreted as confirming previous conclusions about the influence on the decay curves of polarization charges piling up near the electrodes. For short pulses, these charges do not have time to accumulate. This tends to make the slopes approach the fast natural decay of some bands (blue band of a Sylvania cell). For other bands (green band of Sylvania cell), the decreased number of filled traps also tends to make the decay faster for short excitation pulses.

* Also at the University of Maryland.

P15. Electroluminescence in ZnS Single Crystals. D. R. FRANKL, *Sylvania Electric Products Inc.*—Watson *et al.*[1] have shown that 60 cycle half-wave voltage excitation of electroluminescent ZnS single crystals results in emission having two major peaks per cycle. The spectral distributions and absolute intensities of these peaks have been measured by means of a calibrated photomultiplier and a series of interference filters. The two peaks have essentially the same spectrum, a broad peak at about 4500 A, and have intensities of the order of 10^{12} photons/sec in the brightest crystals at average field strengths of the order of 10 kv/cm. The crystal current is almost purely conductive, and is nearly exponential with voltage. The in-phase emission intensity is essentially a function of the current alone.

[1] Watson, Dropkin, and Halpin, Phys. Rev. **94**, 777(A) (1954).

SATURDAY MORNING AT 9:30

Kent 106

(H. A. BETHE presiding)

Mesons

Q1. Photomeson Production from Hydrogen. BERNARD T. FELD, *M.I.T.*—The available data on charged and neutral photomeson production from hydrogen, from threshold to ~450-Mev photons, can be fitted on the assumption of *s*- and *p*-wave meson production only. The most reasonable interpretation requires a resonance in the state of ordinary and isotopic spin $\frac{3}{2}$, positive parity, at a photon energy of ~350 Mev. The observed angular distributions require appreciable electric quadrupole photon absorption, in addition to magnetic dipole absorption, in this state, especially at the higher energies.

The (complex) amplitudes for the absorption processes involved exhibit reasonable dependence on photon energy, with the exception of the phase of the electric dipole absorption which appears to be anomalously large near threshold. An alternative "Yang-type" solution cannot be excluded on the basis of the present data, but the ambiguity could be resolved by the observation of the state of polarization of the recoil protons from the neutral photomeson production.

* Work done as Guggenheim Fellow and Visiting Professor at the Institute of Physics, University of Rome, Italy.

Q2. Pion Photoproduction Ratios. D. C. PEASLEE, *Purdue University.*—Measurements[1] of the pion production ratio $\rho=\pi^+/\pi^-$ from nuclear bombardment by 300-Mev bremsstrahlung have been interpreted in terms of (i) Coulomb field effects; (ii) limitations on the final states of the recoil nucleon; (iii) intrinsic reduction of $p(\gamma,\pi^+)n$ relative to $n(\gamma,\pi^-)p$; (iv) variation of the effective neutron to proton ratio at the nuclear surface. Simple formulas fitted to the data indicate that (i) and (ii) are appreciable for the elements studied; a rough value of $\rho_0\approx 0.9$ results for (iii); no information on (iv) is obtainable from the crude interpretation. A plot of total yields corrected for (i) and (ii) indicates considerable transparency for light nuclei, going over to the usual $A^{\frac{1}{3}}$ law for $A>16$.

[1] Voss, Palfrey, and Haxby, Bull. Am. Phys. Soc. **29** (5), 19 (1954); R. M. Littauer and D. Walker, Phys. Rev. **86**, 838 (1952).

Q3. Photoproduction of π^0 Mesons in Hydrogen.* L. J. KOESTER, *University of Illinois.*—The photoproduction of π^0 mesons at low energies has been investigated by observing the recoil protons from a 2.2-cm diameter liquid hydrogen target. The proton detectors were stacked emulsions placed at an angle of 17.5° with the x-ray beam. Proton energies were obtained by range measurements. The betatron energy was 225 Mev. On the basis of about half of the observed tracks, the differential cross sections obtained for photoproduction of π^0 mesons at a center-of-mass angle of $133°\pm 8°$ are, in units of 10^{-30} cm^2/steradian:

1.3 ± 0.3 at 183 ± 4.5 Mev, 1.4 ± 0.3 at 192 ± 4.5 Mev,
1.7 ± 0.4 at 200.5 ± 4 Mev, and 2.1 ± 0.5 at 208 ± 3.5 Mev.

The energy dependence of the differential cross section at 135° may, in principle, be used together with the total cross section to distinguish between a pure P-wave $(5-3\cos^2\theta)$ angular distribution and an S-wave, P-wave mixture $(A_0+A_1\cos\theta+A_2\cos^2\theta)$. If, however, $A_2\approx 4A_1$, this discrimination is not feasible. The relation of these results to those of other laboratories will be discussed.

* Supported in part by the Office of Naval Research and the U. S. Atomic Energy Commission.

Q4. Elastic Photoproduction of π^0 Mesons for Helium.* E. L. GOLDWASSER, L. J. KOESTER, AND F. E. MILLS, *University of Illinois.*—The activation curve for the photoproduction of π^0 mesons from liquid helium has been observed. Detection of the π^0 mesons was accomplished by observing the π^0 decay γ-ray pairs in two γ-ray telescopes. The betatron maximum energy was varied from 150 to 190 Mev. Conservation of energy requires that all π^0 mesons produced by photons with energies between 138 and 158 Mev arise from the elastic process, $h\nu+\mathrm{He}^4\rightarrow\pi^0+\mathrm{He}^4$. Results of this experiment clearly indicate the production of π^0 mesons by photons in this energy bin. Production of S-wave mesons through this process is forbidden by angular momentum selection rules. Spin flipping interactions are forbidden by the Pauli principle. Therefore P-wave production can arise only through magnetic dipole absorption. For these reasons, a suppression of the cross section for single nucleon interactions is expected. However, a comparison of activation curves for helium and hydrogen indicates roughly equal cross sections per nucleon. A contribution from cooperative interactions of the four nucleons of helium could compensate for the expected suppression. A measurement of this cooperative contribution gives information about the form factor for the nucleons in the helium nucleus.

* Supported in part by the Office of Naval Research and the U. S. Atomic Energy Commission.

Q5. The Scattering of π Mesons by Nuclei. LEONARD S. KISSLINGER.*—The elastic scattering of π mesons by nuclei was calculated using the generalized optical model. This model[1,2] has the simplicity of the old optical model in that the scattering can be described by a potential independent of the individual coordinates of the nucleons and depending only on the coordinates of the scattered particle. It is superior to the old optical model in that the potential describing the elastic scattering depends not only on the nucleon density but also on its gradient. The predominant p-wave dependence of the meson-nucleon scattering necessitates the inclusion of the gradient of the density in the real part of the potential. As is usually done the imaginary part of the potential is assumed to be proportional to the nucleon density. Using a Gaussian density distribution, the scattering of 62-Mev mesons by C^{12} was calculated, the results obtained being in reasonable agreement with experiment.

* National Science Foundation Predoctoral Fellow.
[1] Kenneth W. Watson, Phys. Rev. **89**, 578 (1953).
[2] N. C. Francis and K. W. Watson, Phys. Rev. **92**, 291 (1953).
[3] Byfield, Kessler, and Lederman, Phys. Rev. **86**, 17 (1952).

Q6. Differential Cross Sections for Pion-Proton Scattering at 150 and 170 Mev.* F. FEINER, J. ASHKIN, J. P. BLASER, AND M. O. STERN, *Carnegie Institute of Technology.*—Measurements using counter techniques have been made on the angular distribution of 150-Mev π^+ and π^- mesons scattered by liquid hydrogen. Both the elastic and charge exchange reactions have been observed. The distributions were measured at eight angles ranging from 30° to 157° in the laboratory system. Phase shifts resulting from analysis of the data, as well as conclusions concerning the importance of d-wave scattering will be presented. Preliminary data on similar measurements for 170-Mev π^+ and π^- mesons will also be given.

* Supported in part by the U. S. Atomic Energy Commission.

Q7. Scattering of 165-Mev Pions by Protons.* M. GLICKSMAN AND H. L. ANDERSON, *The University of Chicago.*—The elastic scattering of positive pions, and the elastic and charge exchange scattering of negative pions in liquid hydrogen were measured at 165 Mev. The differential cross sections for these processes were measured, and in addition, the total cross sections were determined from transmission measurements. For π^+ the transmission measurements gave 188.2 ± 5.4 mb, while the integral of the differential measurements was 188.6 ± 11.5 mb. For π^- the integral of the differential elastic scattering cross sections was 22.5 ± 1.5 mb, while for the charge exchange process the integral was 42.5 ± 1.3 mb. From this the total cross section for π^- including the radiative capture process was found to be 65.7 ± 2.0 mb. The total cross section determined from the transmission measurement for π^- was found to be 67.5 ± 1.5 mb. In our preliminary analysis of the data three distinct sets of phase shifts were found with the values:

	Set No. 1	Set No. 2	Set No. 3
α_1	9°	9°	6°
α_3	−18°	−17°	−37°
α_{11}	−7°	−5°	11°
α_{13}	2°	1°	−7°
α_{31}	1°	97°	68°
α_{33}	63°	34°	26°

* Research supported by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

Q8. Scattering of 23-Mev Positive Pions on Hydrogen. JAY OREAR, *Columbia University.*—The 90-Mev π^+ beam of the Chicago cyclotron was slowed down to a mean energy of

25 Mev by absorbers placed 50 inches in front of the 45° deflecting magnet. G5 plates were placed at the conjugate focus, 50 inches behind the magnet. As of September 24, four scatterings on hydrogen had been found with barycentric angles of 79°, 83°, 89°, and 106°. This corresponds to a total cross section of about 4 mb for scatterings greater than 50°. A value of $-2.1°$ is obtained for α_3 by using the recipe ($\alpha_{33}=0.235\eta^3$).[1] For $(-1°<\alpha_3<4°)$, the cross section would be less than 2.4 mb. Independent evidence that α_3 cannot be positive (or near zero) at 23 Mev is the observed angular distribution. Any positive value (or negative value down to $-1°$) of α_3 gives a strong backward scattering which would make the four angles obtained here highly improbable. As α_3 becomes more negative the Coulomb interference changes from destructive to constructive which greatly increases the forward scattering. The proposal[1] that $\alpha_3=-0.11\eta$ is a good fit to all the low-energy data is supported by these preliminary results.

[1] J. Orear, Phys. Rev. **96**, 176 (1954).

Q9. Scattering of 195-Mev Pions by Deuterium.* W. SKOLNIK, *University of Chicago.*—A preliminary measurement of the scattering cross section for 195-Mev negative pions has been made. A liquid deuterium target was placed in an external 195±5 Mev pion beam from the Chicago synchrocyclotron. The attenuation of the beam by the deuterium was measured with four scintillation counters in coincidence. Two small counters were placed before the target and two large counters behind. Sufficient copper absorber was used between the final two counters to cut out proton and deuteron recoils. The attenuation measurement yielded a total cross section of 212±8 mb. Preliminary measurements on the differential cross sections for pions either elastically or inelastically scattered were made and will be described in detail.

* Research supported by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

Q10. Interaction of 46 Mev π^+ Mesons in Deuterium.* D. BODANSKY AND A. M. SACHS, *Columbia University.*—Elastic and inelastic scattering and the absorption of 46+5 Mev π^+ mesons in liquid deuterium have been studied. Out-coming particles are detected at several angles, and their mass and energy are determined by pulse-height analysis in the plastic scintillators of the detecting telescope. Mesons of energy greater than 23 Mev and protons of energy greater than 50 Mev are counted. Pulse heights in three counters are measured for each event by photographing an oscilloscope trace. For events with pulse heights in relevant regions, the ratio of events from the empty target to those from deuterium is 0.1 at 90 deg, 2 at 45 deg, and increases rapidly at smaller laboratory angles. Differential cross sections for all scattering where the scattered meson has energy greater than 23 Mev are 0.6±0.2 mb/sterad, 0.7±0.1 mb/sterad, and 1.15±0.2 mb/sterad in the laboratory system for scattering angles of 45, 90, and 135 degrees respectively. Energy distributions of the scattered mesons are obtained. For the absorption process, $\pi^++D\rightarrow P+P$, differential cross section measurements at five angles are consistent with a distribution of $0.3+1.5\cos^2\theta$ mg/sterad in the center-of-mass system.

* Resesrch supported by joint contract of the Office of Naval Research and the U. S. Atomic Energy Commission.

Q11. Interactions of 1.5-Bev π^- Mesons.* W. D. WALKER† AND J. CRUSSARD, *University of Rochester.*—Further studies[1,2] have been made on π^--P and π^--N interactions at 1.5 Bev. Approximately 25 percent of the π^--P collisions seem to be elastic. A considerable fraction of these elastic scatterings seems to be a diffraction scattering produced by the absorption of the incoming π^- beam in inelastic processes. There is a large angle tail on the angular distribution of the elastically scattered π's which is not accountable as a diffraction scattering. From the angular distribution of the elastically scattered π's and the ratio of inelastic to elastic collisions it seems necessary to suppose that a considerable number of the inelastic collisions occur with impact parameters of 10^{-13} cm or more. This outside edge of the nucleon is rather transparent to the π's however. The inelastic collisions usually result in the production of a single additional π. The angular distributions of the products do not seem to be consistent with either a statistical model or an excited nucleon[3] model of meson production.

* Supported by the U. S. Atomic Energy Commission.
† Now at Physics Department, University of Wisconsin.
[1] Crussard, Walker, and Koshiba, Phys. Rev. **94**, 736 (1954).
[2] Walker, Crussard, and Koshiba, Phys. Rev. **95**, 852 (1954).
[3] S. J. Lindenbaum and L. C. L. Yuan, Bull. Am. Phys. Soc. **29**, No. 4, 50 (1954).

Q12. Search for Improbable Meson Decays.* S. LOKANATHAN AND J. STEINBERGER, *Columbia University.*—We have searched unsuccessfully for two possible meson decay processes with apparatus considerably more sensitive than has heretofore been used. In order to detect the process $\mu^+\rightarrow e^++\gamma$, π^+ mesons monitored by a counter telescope were allowed to come to rest in a carbon target. Two detectors are placed at opposite sides of the target, one sensitive to the 50-Mev electrons, the other made sensitive to the γ rays by means of $\frac{1}{4}$ in. of Pb converter. The system is calibrated by means of electrons from normal μ decay. We place an upper limit of 2×10^{-5} for the fraction of μ mesons which decay in this way. In order to detect the electrons in the process $\pi^+\rightarrow e^++\nu$, and to separate them from the accompanying μ-decay electrons, positive pions are stopped in a thin polyethylene target. With a 4-counter telescope, we measure the absorption spectrum in polyethylene of all electrons emerging from the target, as well as that fraction which comes not later than 5×10^{-8} sec following a pulse in a telescope in the incident beam. Comparison of the two absorption curves makes it possible to distinguish the 70-Mev π^+-e^+ electrons from the μ-decay spectrum. We find that the fraction of π's decaying in this fashion is less than 5×10^{-5}.

* This work was performed under the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

SATURDAY MORNING AT 9:30

Eckhart 133

(JOHN MARSHALL presiding)

Reactions of Transmutation, I

R1. Search for Excited States of Be^8. R. E. HOLLAND, D. R. INGLIS, AND F. P. MOORING, *Argonne National Laboratory.*—In an attempt to verify the existence of some of the reported extra states of the simple nucleus Be^8, further[1] momentum analyses have been made of two reactions under various conditions. The reaction $B^{10}(d,\alpha)Be^8$ has been ob-

served with a solid-backed target at several angles between 60° and 120° and bombarding energies between 2 and 3.2 Mev. The reaction B^{11} $(p,\alpha)Be^8$ has been observed under similar conditions and also with a thin-backed natural B target near the forward direction. In spite of rather good resolution and statistics, no evidence has been found for any excited state except the broad 3-Mev state up to about 10 Mev. At an energy corresponding in $B^{11}(p,\alpha)$ to 7 Mev in Be^8 a sharp alpha group is found which has been shown by comparison with a B^{10} target to arise from an intense reaction in the B^{10} content of the natural B target.

[1] R. Malm and D. R. Inglis, Phys. Rev. **92**, 1326 (1953).

R2. The $B^{11}(n,\alpha)Li^8(\beta)Be^{8*}(2\alpha)$ Reaction from 12 to 20 Mev.* G. M. Frye, Jr., A. H. Armstrong, and L. Rosen, *Los Alamos Scientific Laboratory.*—Ilford 200-μ C-2 plates loaded with B^{11} were exposed to monoenergetic neutrons produced at various angles to the 3.5-Mev deuteron beam of the large Los Alamos electrostatic accelerator incident upon a tritium gas target. The plates were then scanned for the distinctive "hammer stars" resulting from the reaction $B^{11}(n,\alpha)Li^8(\beta)Be^{8*}(2\alpha)$. A total of 442 such events were found which satisfied the requirements of conservation of energy and momentum. Using Ilford's data for the B^{11} loading, one obtains the following cross sections: $E_n=12.5$ Mev, $\sigma=29\pm7$ mb; 13.0 Mev, 42 ± 8 mb; 14.7 Mev, 30 ± 6 mb; 15.4 Mev, 41 ± 8 mb; 16.8 Mev, 21 ± 5 mb; 17.5 Mev, 26 ± 5 mb; 18.8 Mev, 21 ± 4 mb; 19.7 Mev, 16 ± 3 mb; 19.9 Mev, 15 ± 3 mb. These cross sections do not include the contribution from the Be^8 ground state, as its disintegration energy of 0.1 Mev is not enough to given perceptible alpha tracks. In essentially all the cases Li^8 was left either in the ground state or in the first excited state at 1 Mev. The values for the excitation energy of Be^8 were similar to those obtained previously,[1] showing the broad level at 3 Mev and possibly additional levels at 4.3 and 7.4 Mev.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] F. C. Gilbert, Phys. Rev. **93**, 499 (1954).

R3. Alpha-Alpha Angular Correlation in $B^{11}(p,\alpha\alpha)He^4$.* E. H. Geer,† E. B. Nelson, and E. J. Wolicki,† *State University of Iowa.*—The angular correlation was measured at proton energies of 163 and 290 kev with thin targets on thin backings, in a plane normal to the proton beam. The shape of the 2.9-Mev level was estimated from the alpha energy spectrum,[1] and the theoretical correlation functions were integrated over the level. The experimental correlations, expressed in terms of the center-of-mass angle, were, for 163 kev, $W=1-1.97\cos^2\theta+1.28\cos^4\theta$, and, for 290 kev, $W=1+1.62\times\cos^2\theta-1.25\cos^4\theta$. The data at 163 kev are consistent with a spin of 2+ in C^{12} and 2+ but not 0+ in Be^8. The data at 290 kev cannot be explained on the basis of a pure 1−, 2−, or 3+ state in C^{12} but probably result from an interference between the states of 0.67 and 1.4 Mev.

* Supported in part by the U. S. Atomic Energy Commission.
† Now at the Naval Research Laboratory.
[1] W. Whaling (private communication).

R4. Angular Distributions and Excitation Functions of $C^{12}(d,p)$ Reaction. K. W. Jones, M. T. McEllistrem, R. A. Douglas, D. F. Herring, and E. Silverstein, *University of Wisconsin.*—Measurements were conducted in a large (4 ft×5 ft) gas scattering chamber. A gridded ion chamber mounted on a 23 in. rotating arm served as principal detector. Differentially pumped gas targets (C_3H_8 or C_4H_{10}) were used to obtain absolute cross sections good to about 6 percent. Excitation curves for $C^{12}(d,p)C^{13}$ were taken at 25, 83, and 161 degrees from 1.857 to 3.45 Mev and at 54, 125, and 154 degrees from 2.58 to 3.3 Mev. Resonances occurred at 2.05, 2.35, 2.51, (2.67)?, 2.74, (2.92)?, 3.01, and 3.10 Mev. Angular distributions were taken on and off several of the resonances. At $E_d=1.86$ Mev the angular distribution showed a large back angle cross section (21 mb at 145 degrees C.M.) with a small forward angle peak (7 mb) at 25 degrees C.M., which peak corresponds to the first stripping maximum expected on Butler's theory for $l_n=1$. As the energy was increased the forward stripping peak cross section increased and became larger than the back angle peak. The magnitude of the stripping maxima changed markedly when taken on and off observed resonances; constructive and destructive interference of stripping and resonant contributions is indicated.

R5. Energy Spectrum of Photoprotons from Carbon. W. E. Stephens and A. K. Mann, *University of Pennsylvania.*—The photoprotons ejected from a 6 mg per cm² thick carbon foil by 23-Mev bremsstrahlung have been observed in nuclear emulsions. The ranges of 408 protons which entered the emulsions in the proper direction were measured. The proton energy distribution has a peak at 5.5 Mev and a width at half-maximum of about 2.8 Mev. These values confirm the previous determination[1] of the giant resonance in carbon which had been obtained from yield curve data. The width of the proton spectrum is consistent with transitions from a single broad level in C^{12} to the ground state of B^{11} but transitions to the first excited state of B^{11} appear to be inhibited.

* Supported in part by the Air Research and Development Command.
[1] J. Halpern and A. K. Mann, Phys. Rev. **83**, 370 (1951).

R6. Q Values for the $O^{17}(d,p)O^{18}$ and $O^{18}(d,p)O^{19}$ Reactions. H. D. Holmgren, T. D. Hanscome, and D. K. Willett, *Naval Research Laboratory.*—The Naval Research Laboratory 60° magnetic spectrograph has been employed to study the energies of the protons emitted from isotopically enriched targets[1] of oxygen bombarded with deuterons from the *NRL* 2-Mev Van de Graaff generator. Targets of both normal and enriched oxygen were studied to identify the proton groups from O^{17} and O^{18}. The energies of the reaction protons were measured for 1.390 and 1.976 Mev incident deuterons at an angle of 90° to the direction of the beam. In addition to the proton groups from O^{16} and carbon, three intense groups and two very weak groups of protons were observed when the enriched oxygen targets were bombarded. The three intense groups were assigned to the $O^{18}(d,p)O^{19}$ reaction with Q values 1.735 ± 0.008, 1.641 ± 0.008, and 0.264 ± 0.013 Mev. Since the energies of the two weak groups were considerably higher than the energy expected for the ground-state transition of the $O^{18}(d,p)O^{19}$ reaction, these groups were attributed to the $O^{17}(d,p)O^{18}$ reaction with Q values 3.393 ± 0.016 and 3.861 ± 0.016 Mev. The Q values for the $O^{18}(d,p)O^{19}$ reaction are in agreement with the work at Minnesota and Cal. Tech.[2] The two proton groups attributed to the $O^{17}(d,p)O^{18}$ reaction indicate levels in O^{18} at 1.977 and 2.445 Mev above the ground state.

[1] We are indebted to A. O. C. Nier for furnishing the enriched oxygen and to the Minnesota Van de Graaff group for helping in preparing the targets.
[2] Stratton, Famularo, Holmgren, and Stuart, Bull. Am. Phys. Soc. **29**, 5 (1954); Thirion, Cohen, and Whaling, Bull. Am. Phys. Soc. **29**, 6 (1954).

R7. Gamma-Ray Thresholds in the $F^{19}(d,n\gamma)Ne^{20}$ Reaction. J. W. Butler, *Naval Research Laboratory.*—When an excited nucleus decays by gamma emission to the ground state following the emission of a neutron at threshold, then the threshold in question may be considered also a "gamma-ray threshold." Two such thresholds have been observed by bombarding a thin target of CaF_2 with deuterons from the NRL 2-Mev Van de Graaff generator, and counting the gamma pulses between 9.7 and 11.9 Mev in a 3-in.×3-in. sodium iodide crystal. There are breaks in the excitation curve at 1.15- and 1.35-Mev bombarding energy indicating levels in Ne^{20} at 11.69 and 11.87 Mev, respectively. Both levels appear to decay to the ground state.

R8. Excitation Functions of Radioactive Products from the Interaction of High-Energy Protons with Lead.* E. BAKER, A. CARETTO, J. CUMMING, G. FRIEDLANDER, J. HUDIS, AND R. WOLFGANG, *Brookhaven National Laboratory.*—Excitation functions of radionuclides produced by proton bombardment of lead between 0.6 and 3 Bev are presented. Yields of isotopes of F, Na, Mg, and P increase rapidly from the order of 10 microbarns at 600 Mev to the order of a millibarn at about 2 Bev. Thus at these high energies production of such light elements—which cannot result from the usual spallation or fission processes—becomes a relatively probable event. In the medium mass region, from Mn to Ba, cross sections of neutron excess isotopes (as produced by 340 Mev Bi fission[1]) remain approximately constant or decrease by about a factor of two with increasing energy. By contrast yields of neutron deficient nuclides increase rapidly until at about 2 Bev they become comparable with those of the neutron excess nuclides. No clearly defined fission peak as appears with Bi at 340 Mev was found with Pb at Bev energies.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] W. F. Biller, UCRL 2067.

SATURDAY MORNING AT 9:30

Cobb 110

(T. H. OSGOOD presiding)

Invited Paper

S1. Ultrasonic Light Modulators for Spectroscopy and the Measurement of Very Short Time Intervals. E. A. HIEDEMANN, *Michigan State College.* (30 min.)

General Physics, I

S2. Intensity Distribution Among Spectral Orders in a Grazing Incidence Spectrograph.* D. E. BEDO AND D. H. TOMBOULIAN, *Cornell University.*—Relative intensity measurements in soft x-ray continuous spectra emitted by relativistic electrons or x-ray targets require a knowledge of the distribution of intensity among various spectral orders. An investigation was undertaken for the comparison of the beam intensity in a given order with that of the incident beam. The narrow emission bands of C, Be, and Al were used as sources. For the particular spectrograph equipped with a lightly ruled grating (grazing angle of incidence fixed at 4.64°) theoretical considerations[1] predict the enhancement of spectral intensity in orders zero, one, and two at $\lambda = 35$, 55, and 90 A, respectively. Furthermore the fraction of the incident intensity diffracted into the first order should vary from 0.5 percent at 60 A to 9 percent at 200 A; in the second order from 1 percent at 100 A to 6 percent at 200 A. Intensity ratios based on the synchrotron continuum, emission bands, and line spectra compare favorably with the calculated values.

* Supported by the Office of Ordnance Research, U. S. Army.
[1] Calculations by Dr. G. C. Sprague (to be published).

S3. The Determination of Polydisperse Aerosol Size Distributions from the Analysis of Light Scattering Data.* T. L. GILBERT, *Armour Research Foundation of Illinois Institute of Technology.*—The problem of calculating the size distribution, $n(r)$, of a polydisperse aerosol from the light scattered at various angles, $I(\cos\theta)$, or the extinction at various wavelengths, $I(2\pi/\lambda)$, is equivalent to solving an integral equation of the first kind, $I(x) = \int K(x,r)n(r)dr$, where $K(x,r)$ is the scattered light or extinction for a monodisperse aerosol with particles of radius r. If the function, $I(x)$, obtained from experimental measurements is used, this equation will, in general, have no solution because of experimental errors. As a consequence, previously used methods, which attempt to approximate this nonexistent solution, are completely unreliable. An exact solution of a modified equation, obtained by using a kernel derived from the bilinear expansion of the exact kernel by discarding all but a finite number of terms, will exist. A new approximate method will be presented for calculating that size distribution which represents the optimum compromise between experimental errors and the error introduced by using the approximate kernel.

* Work supported by Geophysics Research Directorate of the Air Force Cambridge Research Center.

S4. A Mass Spectrometric Study of Gaseous Species in the $Si-SiO_2$ System. RICHARD F. PORTER AND PAUL SCHISSEL, *University of Chicago,* AND MARK G. INGHRAM, *University of Chicago, and Argonne National Laboratory.*—A combination of mass spectrometric and Knudsen effusion techniques have been employed to study the molecular composition of the equilibrium vapor over solid SiO_2 and $Si-SiO_2$ mixtures at temperatures between 1500°K and 1950°K. Gaseous molecules effusing from the Knudsen cell enter directly into the ionization chamber of the mass spectrometer.[1] Ion currents of SiO^+ and SiO_2^+ were observed. Appearance potentials for the two species are 10.8 ± 0.5 and 11.7 ± 0.5 ev, respectively. A peak at mass 88 is tentatively ascribed to $Si_2O_3^+$. The low voltages required to produce SiO_2^+ together with temperature dependence measurements show that SiO_2^+ must be formed by direct ionization of effusing SiO_2 gas and cannot be formed in a secondary mechanism involving SiO^+. With the calculated partial pressure of SiO inside the Knudsen cell and estimating relative ionization cross sections of 1 and 1.5 for SiO^+ and SiO_2^+, respectively, we obtain the partial pressure of SiO_2 from the ion current ratio of SiO_2^+ to SiO^+. With an estimated uncertainty of within a factor of three, the partial pressure of SiO_2 gas is 5×10^{-7} atmos over SiO_2 solid at $T = 1925$°K. From the temperature dependence curve for SiO_2, we obtain for SiO_2 (quartz) $= SiO_2$ (gas); $\Delta H_{298}° = 130 \pm 7$ kcal.

[1] W. A. Chupka and M. G. Inghram (to be published).

S5. Equilibrium Charge Distribution of Energetic Nitrogen Ions. H. L. REYNOLDS, L. D. WYLY,* AND A. ZUCKER, *Oak Ridge National Laboratory.*—The equilibrium charge distribution of nitrogen ions in Formvar was measured as a function of the nitrogen energy from 6 to 26 Mev. The fringing magnetic field of the cyclotron was used to separate the charge groups resulting from the passage of the nitrogen ion beam through Formvar foils of sufficient thickness to insure an equilibrium charge distribution. At 26 Mev, 41 percent of the

ions are completely stripped while at 10 Mev 3.5 percent are completely stripped. The ratio of the loss to capture cross sections for the first two electrons is proportional to $V^{3.9}$. The ratio of the loss to capture ratio for the third electron is proportional to $V^{2.7}$. The capture and loss cross sections for the first electron are equal at an energy of 28.2 Mev, and for the second electron at 13.3 Mev.

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S6. Measurement of the Ionization Yield of Low Energy Ions in a Gas.* RALPH A. LOWRY AND GLENN H. MILLER, *Iowa State College.*—A large cylindrical ionization chamber has been used to study the ionization yield of 50 to 250 kev ions in various gases. The ions are selected from the kevatron beam by a magnetic and electrostatic analyzer and enter the chamber by means of a 0.004 inch diameter open window. A differential pumping system permits pressures up to 10 mm Hg to be maintained in the chamber. The chamber is alternately operated as a proportional counter and an ionization chamber to measure the rate with which the primary ions enter the chamber and the ionization produced by them, respectively. A detailed description of the apparatus and measuring technique will be given. The results for protons in nitrogen gas will be presented.

* Work was performed in the Ames Laboratory of the U. S. Atomic Energy Commission.

S7. Specific Heat of He^3-He^4 Solutions. P. J. PRICE AND P. B. LINHART, *IBM Watson Laboratory.*—The effect of small amounts of dissolved He^3 isotope on the specific heat of liquid helium is of interest to the study of quantum liquids. No direct measurements have been reported, but the molar specific heat C may be calculated from measurements on the saturated vapor by means of a thermodynamic formula. For small concentrations X of He^3

$$C(X,T)=(1-X)C(0,T)+RXf(T)+O(X^2),$$

where

$$f=5/2-Td^2/dT^2[T\ln(\partial p_3^*/\partial X)_{X=0}].$$

We have calculated f from 1.2° to the lambda point, using values of the partial fugacity $p_3^*(X,T)$ calculated from Sommers' data.[1] f exceeds the "ideal gas value" $\frac{3}{2}$ appreciably at 1.6°, and rises steeply to more than 30 near the lambda point. The interpretation of this result will be discussed.

[1] H. S. Sommers, Jr., Phys. Rev. **88**, 113 (1952).

S8. The Mechanism of Photochemical Reactions Catalyzed by Red-Mercuric Sulfide. L. L. GROSSWEINER AND S. GORDON, *Argonne National Laboratory.*—Visible light irradiation of suspended red-HgS in acid solutions of ferrous-ferric sulfate will induce oxidation in the presence of oxygen and reduction in oxygen-free systems.[1] Continued work shows that similar irradiations in distilled water containing oxygen will induce hydrogen peroxide formation. The initial yields are linear with absorbed light intensity, while the maximum yields are limited by a photoactivated back-reaction which destroys hydrogen peroxide. It is consistent with these and the earlier results to assume that the primary products are H and OH formed respectively from the capture of conduction electrons from excited HgS by absorbed hydrogen ions and from the anodic discharge of HgS particles by water. It is believed that the OH recombines to water and oxygen, not hydrogen peroxide. For these primary reactions to be energetically favorable, it is estimated that the energy of an electron in a low conduction level of HgS is about 4 to 5 ev compared to vacuum. The energetics of the over-all photochemical conversion of water and oxygen to hydrogen peroxide depends only on the valence-to-conduction band gap and is exothermic for this system.

[1] L. I. Grossweiner and S. Gordon, J. Chem. Phys. **22**, 1139 (1954).

S9. Calculation of the Compressibility of Polyethylene from the Energy of Interaction between $(-CH_2-)$ Groups. WERNER BRANDT, *E. I. Du Pont de Nemours & Company.*—Polyethylene consists essentially of long $(-CH_2-)$ chains arranged in a partly crystalline structure. The crystalline regions are assumed to be interconnected by chains penetrating regions of lower degrees of order. Considering the interaction of all chains in such an imperfect lattice, a semiempirical potential energy function of molecular interaction is derived under the assumption that each $(-CH_2-)$ group of a chain interacts with each of the surrounding lattice groups according to a Lennard-Jones potential $4\epsilon[(\sigma/r)^{12}-(\sigma/r)^6]$. The intermolecular force constants of a $(-CH_2-)$ group are determined from the density of polyethylene and from the heat of sublimation per $(-CH_2-)$ group at 0°K. They are found to be $\sigma=4.19$A and $\epsilon/k=38.4$°K. The volume dependence of the potential function leads to the compressibility of polyethylene and its dependence on pressure. The theoretical results are in agreement with experimental data[1-3] up to 40 000 kg/cm².

[1] P. W. Bridgman, Proc. Am. Acad. Arts Sci. **76**, 71 (1948).
[2] W. Parks and R. B. Richards, Trans. Faraday Soc. **45**, 203 (1949).
[3] C. E. Weir, J. Research Natl. Bur. Standards **46**, 207 (1951).

S10. Direct Production of Spectroscopic Specimens from Single Crystals by Controlled Growth from a Vapor; Infrared Absorption Anisotropy and Induced Molecular Motion in a Single Crystal of Benzene. SOLOMON ZWERDLING, *Lincoln Laboratory, M.I.T.*, AND RALPH S. HALFORD, *Columbia University.*—A method has been developed for growing from the vapor phase, thin section single crystals of very low melting substances for use in polarized infrared spectrometry. The method consists of evacuating a special cell, developing a thermal gradient across it at low temperature, and controlling vapor admittance by capillary flow until the critical nucleation pressure is reached. Following nucleation, growth is completed below the critical pressure. A single crystal of benzene 100μ thick and 300 mm² area was grown in 15 hours. The extinction axes were determined between crossed polaroids using visible light. Polarized and unpolarized infrared spectra were measured from 650 to 4000 cm^{-1}. Spectra interpretation was based upon D_{6h} point symmetry for benzene vapor, C_i site symmetry and V_h^{15} factor group symmetry for the unit cell containing 4 molecules. Since crystalline benzene is biaxial orthorhombic, the interpretation is simplified. The results indicated that incident radiation was parallel to the b axis, and the a and c axes were parallel to the extinction axes. Absorption due to "intrinsic" moments and to crystal "induced" moments were analyzed in different orders of approximation. Splitting of frequencies under the "static" crystal field and under site-factor group correlations were examined, as well as several additional spectral features.

S11. Normal Coordinate Treatments and Calculated Thermodynamic Properties of Phosphoryl Chloride, Phosphoryl Fluoride, Thiophosphoryl Chloride, and Thiophosphoryl Fluoride.* JOSEPH S. ZIOMEK, EDWARD A. PIOTROWSKI, AND EDWARD N. WALSH, *De Paul University.*—The infrared and Raman spectra for phosphoryl chloride, phosphoryl fluoride, thiophosphoryl chloride, and thiophosphoryl fluoride were collected and examined for the most probable values for the wave numbers, intensities, and depolarization factors. The values adopted for the fundamentals are as follows: for $POCl_3$, 192.85, 267.39, 337.44, 486.24, 581.2, and 1289.9 K; for POF_3, 337, 476, 483, 875, 982, and 1395 K; for $PSCl_3$, 172, 247, 247, 430, 538, and 753 K; and for PSF_3, 276, 402, 440, 695, 874, and 940 K. Also normal coordinate treatments on the basis of the most probable model C_{3v} were conducted for these same molecules. These treatments gave the above listed wave numbers as those of the fundamentals.

Moreover, the F matrix elements obtained for these molecules were determined in such a manner that those potential constants for the PCl_3 group had nearly the same values in both $POCl_3$ and $PSCl_3$, those for the PF_3 group had nearly the same values in both POF_3 and PSF_3, the one for the PO group had nearly the same value in both $POCl_3$ and POF_3, and the one for the PS group had nearly the same value in both PSF_3 and $PSCl_3$. Finally, the above spectral data were used to calculate the values of the thermodynamic properties for these substances up to a rigid rotator harmonic oscillator approximation for temperatures from 200°K to 1000°K.

* Supported by the Office of Ordnance Research.

SATURDAY MORNING AT 9:30

Mandel Hall

(JOHN BARDEEN presiding)

Symposium of the Division of Solid-State Physics

T1. Recent Experiments on High-Pressure Phenomena at Chicago. A. W. LAWSON, *University of Chicago.* (30 min.)

T2. P-V Isotherms of 10 000 Atmospheres st 4.2°K for Four Alkali Metals and Some Condensed Gases. C. A. SWENSON, *M.I.T.* (30 min.)

T3. Properties of Germanium and Silicon at High Pressures. H. BROOKS, *Harvard University.* (30 min.)

T4. Effect of Hydrostatic Pressure on the Superconducting Transition. M. D. FISKE, *General Electric Research Laboratory.* (30 min.)

SATURDAY MORNING AT 9:30

Judd 126

(K. M. WATSON presiding)

Invited Papers in Theoretical Physics

U1. Neutron-Proton Mass Difference and Structure of the Nucleon. R. G. SACHS, *University of Wisconsin* (30 min.)

U2. Nuclear Saturation and the Independent-Particle Model of the Nucleus. K. A. BRUECKNER, *Indiana University.* (30 min.)

U3. Calculations of Energy-Levels for Intermediate Nuclei. K. W. FORD, *Indiana University.* (30 min.)

U4. Some Considerations Concerning Relstivistic Two-Particle Wave-Equations. Z. V. CHRAPLYVY, *St. Louis University.* (30 min.)

SATURDAY AFTERNOON AT 1:30

Oriental 104

(CYRIL S. SMITH presiding)

Metals

V1. Diffusion of Copper and Zinc in Ordered and Disordered CuZn.* ALAN B. KUPER AND CARL T. TOMIZUKA, *University of Illinois.*—Radioactive tracer diffusion measurements have been made using Cu^{64} and Zn^{65} diffusing into single crystals of CuZn of approximately 48 atom percent Zn (β brass). At this composition, the alloy orders at about 466°C (T_c). β brass orders rapidly with no change in volume or structure. Diffusion coefficients have been determined at 7 points between about 350° and 850°C for each element. In the disordered phase, data above T_c+10°C may be represented by: $D_{Zn}=0.013e^{-21200/RT}$; $D_{Cu}=0.020e^{-23200/RT}$. The transition from D to D' is being studied from 470° to 430°C. In the ordered phase, preliminary results indicate that below T_c-55°C: $D_{Zn}'\cong 77\cdot e^{-35600/RT}$; $D_{Cu}'\cong 5.6e^{-32900/RT}$. From these data it can be seen that $D_{Zn}'\rightarrow D_{Cu}'$ at low temperatures. The existence of a Kirkendall effect in β brass[1] rules out an interchange mechanism for diffusion. The low temperature data suggest a vacancy rather than an interstitial mechanism.

* Supported in part by the U. S. Atomic Energy Commission.

[1] R. Resnick and R. W. Balluffi, private communication.

V2. Effect of Low Concentrations of Impurity on Diffusion in Silver. E. SONDER, *University of Illinois.*— In order to obtain information on the effect of impurities in the one percent range on the activation energy of diffusion, diffusion coefficients for antimony and silver tracers into single crystals of silver doped with antimony are being measured. Partially complete data show the following. 1. The diffusion rate of antimony tracer is not changed by adding as much as 0.8 percent antimony impurity to the silver lattice. 2. There is an appreciable (about 50 percent) increase in the diffusion rate of silver tracer in these alloys. There seems to be little if any change in the activation energy for silver self-diffusion in these alloys of up to 1.6 percent antimony. This result is similar to that obtained on the silver lead system by other investigators.[1]

[1] Hoffman and Turnbull, J. Appl. Phys. **23**, 1409 (1952).

V3. Interpretation of Dimensional Changes on Dezincification of Alpha Brass. DAVID D. VAN HORN AND WILLIAM J. COOLEY, *Knolls Atomic Power Laboratory.**—Small wires and square plates of alpha brass were dezincified in vacuum at various temperatures and the dimensional changes were followed as a function of the amount of zinc removed. Dimensional changes in both geometries were found to be linear functions of the amount of zinc removed. Since these relationships are independent of temperature, it is reasonable to assume that all the vacancies introduced remain within the material, "precipitating" out to form the observed porosity. If one assumes no volume change results on agglomeration of vacancies, the observed dimensional changes can be related to the accumulated lattice strain resulting from the introduction of vacancies. Greater dimensional changes in the diffusion direction are attributed to the additional effect of loss of surface lattice sites due to the concurrent diffusion of copper atoms. The ratio of the intrinsic diffusivities of copper and zinc is calculated along with the lattice strain introduced by vacancies. The lattice strain is 0.12 times the concentration of vacancies; the ratio of diffusivities of copper to zinc is 0.11.

* Operated by the General Electric Company for the U. S. Atomic Energy Commission.

V4. Effect of Quench on the Structure of Au−Cd. MONROE S. WECHSLER, *Oak Ridge National Laboratory.*—Experiments initiated at Columbia University and continuing at ORNL have shown that quenches from 450°C cause a ten percent increase in the electrical resistivity of Au−Cd of approximately 50 atomic percent composition. This alloy is ordered in the Cs−Cl structure at temperatures several degrees above room temperature. At-temperature x-ray spectrometer measurements were made in the range of temperatures from room temperature to approximately 15°C below the melting point (~620°C) in order to determine whether the increase in resistivity is the result of the quenching-in of a less ordered structure or possibly to a new phase formed at the high temperature. It was found, however, that the alloy is highly ordered at temperatures near the melting point and that no new phase is formed. Experiments were also performed on the annealing kinetics of the effect of quench. It was found that the increase in resistivity anneals out in the order of 100 minutes at 70°C and that the process has an activation energy of 0.6 ev. Interpretation will be given in terms of the motion of lattice vacancies.

V5. Expansion of Copper Bombarded by 19-Mev Deuterons. HENRY A. KIERSTEAD, *Argonne National Laboratory.*— The deuteron bombardment-induced expansion of copper reported earlier[1] has been investigated in more detail by using an improved apparatus of greater sensitivity and reliability, and the annealing characteristics of the volume change have been studied. Bombardment by 1.15×10^{17} 19-Mev deuterons per cm² at liquid nitrogen temperature produces a volume increase of 0.034 percent, averaged over the range of the deuteron. About 10.8 percent of this effect recovers on annealing to −105°C, none between −105°C and −25°C, 2.9 percent between −25°C and 0°C, none between 0°C and 190°C, 3.6 percent between 190°C and 260°C, and 2.9 percent just below 400°C. About 80 percent of the volume change remains after annealing to 400°C. Using the Seitz theory to calculate the number of atoms displaced per 19-Mev deuteron, we find that the final volume change corresponds to about one-tenth of an atomic volume per displaced atom. In the range studied the volume change is about proportional to the bombardment. Room-temperature bombardment produces only about one-tenth as much volume change as is produced by liquid nitrogen bombarment followed by annealing to room temperature. Dr. Siegel of this laboratory reports no change in the lattice constant, within the error (0.02 percent) of the x-ray measurement.

[1] W. R. McDonell and H. A. Kierstead, Phys. Rev. **93**, 247 (1954).

V6. Effect of Vacancies and Interstitials on the Electrical Properties of Copper. F. J. BLATT, *University of Illinois*— In order to interpret resistance measurements on metal. during irradiation and upon subsequent anneal, a knowledge of the effect on the resistivity of a small concentration of vacancies and interstitials is necessary. The change in resistivity due to vacancies in copper has been calculated by Jongenburger.[1] In an analogous manner, the change in resistivity due to interstitials was obtained. The scattering potential used was the Hartree potential of singly ionized copper, and the shielding was adjusted to give the correct Friedel sum.[2] The effect of the relaxation of the lattice was neglected.[3] The result, $\Delta\rho_{\text{int}}=1.4$ μohm-cm/atom percent, which is nearly the same as $\Delta\rho_{\text{vac}}=1.25$ μohm-cm/atom percent,[1] does not agree with the conclusions of Overhauser.[4] The effect of lattice imperfections on the thermoelectric power[5] has also been determined.

[1] P. Jongenburger, Appl. Sci. Research **B3**, 237 (1953).
[2] J. Friedel, Phil. Mag. **43**, 153 (1952).
[3] D. L. Dexter, Phys. Rev. **87**, 768 (1952).
[4] A. W. Overhauser, Phys. Rev. **94**, 1551 (1954).
[5] C. A. Domenicali and F. A. Otter, Phys. Rev. **95**, 1134 (1954).

V7. Formation Energy of Lattice Vacancies in Gold.* J. W. KAUFFMAN AND J. S. KOEHLER, *University of Illinois.*—High purity (99.999 percent or better) large grained polycrystalline gold wires were rapidly quenched from given temperatures in the range 500°C to 900°C to liquid nitrogen temperature. The wires were heated in a helium atmosphere by electric current and quenched by a jet of cooled helium gas; they were then immediately immersed in liquid nitrogen. The quench produces an increase in the electrical resistance up to 0.8 percent which is completely annealed out at higher temperatures. The increase in resistance is interpreted as due to lattice vacancies that are in equilibrium at the temperature at which the quench is made. The slope of the log of the resistance increase *versus* the reciprocal of the temperature at quench gives 1.28 ± 0.03 ev for the energy of formation of a vacancy. For a particular specimen the data show a sharp break at low temperatures to a plateau. The residual resistance at 4°K was measured in order to estimate the relative purity of the specimens. The lower the temperature at which the plateau appeared the lower was the impurity content. Appreciable recovery occurs in the range −20°C to 0°C.

* This research reported in part by the U. S. Atomic Energy Commission.

V8. Vibration Spectra and Specific Heats of Cubic Metals. Part I: Theory and Application to Sodium. A. B. BHATIA,* *National Research Council, Canada.*—A model for monovalent metals is proposed on the basis of which the secular equations determining the frequencies of the normal modes of vibration

are derived for body- and face-centered cubic metals. In contrast to the two force constants occurring in the Born-von Karman model, these equations contain three force constants which may be identified with the three independent elastic constants of a cubic metal. The limitations of the model are discussed. In Part III of this paper, the frequency spectrum of sodium and hence its specific heat C_v at constant volume is calculated by solving these secular equations. It is found that the agreement between the observed and calculated values of C_v is more satisfactory in the entire relevant (and especially at low temperatures) temperature range than that obtained by Bauer[1] using the customary two force constant model.

* National Research Laboratories Postdoctorate Fellow.
[1] E. Bauer, Phys. Rev. **92**, 58 (1953).

V9. A Theory of Steady-State Creep Based on Dislocation Climb. J. WEERTMAN, *Naval Research Laboratory* (introduced by J. R. WEERTMAN).—A theory of steady-state creep is developed using Mott's model of dislocations climbing over barriers. The assumed rate-controlling process is the flow of vacancies from barriers where they are being produced by dislocation climb to barriers where they are being destroyed. The concentration of vacancies at a barrier is determined by equating the work done when a dislocation climbs in a stress field in which it moves in the slip direction as it climbs to the change in the Gibb's free energy caused by the creation or destruction of vacancies. If the barriers are immobile dislocations the creep equation that results from the analysis is: creep rate $=$ const $(\sigma^m/kT)\exp(-Q/kT)$ where σ is the stress, m is a constant (reasonable values being $4<m<6$), Q is the activation energy of self-diffusion, and k and T have their usual meanings. This equation should be valid only in the approximate stress range of 10^7 to 4×10^8 dynes/cm^2. At higher stresses the theory predicts that the creep rate will increase at a greater rate with stress; at lower stresses with a smaller stress dependence.

V10. Internal Friction in Some Fe-Al Alloys. C. WERT, *University of Illinois.*—The internal friction of alloys of Fe and Al close to the composition Fe_3Al has been partially investigated. Two well-defined peaks of damping as a function of temperature have been observed in polycrystalline specimens. For a frequency of about 1 cps, one of these peaks occurs near 700 deg C, the other near 500 deg C. The high-temperature peak had a high maximum, the lower peak had a much smaller maximum. These peaks are tentatively ascribed to the grain-boundary relaxation and the short-range-order relaxation, respectively. In addition to these well defined peaks at these relatively high temperatures, there is a further component of damping at lower temperatures which is almost certainly of magnetic origin. It is strongly amplitude dependent and exists below the magnetic Curie temperature (some 300 deg C) at least as far down as room temperature. It is not present in hot-rolled material but appears after such material has been given a high temperature anneal.

V11. Properties of CdS Films Deposited in Vacuo. ARTHUR BRAMLEY, *A. B. Du Mont Laboratories.*—The presence of metallic Cd in evaporated films of CdS was reported recently by Gottesman and Ferguson. The present experiments indicate that the properties of CdS films depend strongly on evaporation techniques. CdS evaporated on cold surfaces contains conducting impurities whereas no evidence of impurities was found in fractionally distilled CdS evaporated on hot surfaces. Films with impurities have low photoconductive sensitivity and low dark resistance while films evaporated on hot surfaces have high dark resistance and a sensitivity comparable to the best CdS crystals prepared by Frerichs method. Baking both types of films in air at 300°C for 2 hours had no permanent effect on either dark resistance or sensitivity, although the dark resistance of the insensitive variety increased temporarily by a factor of 10. No loss of sensitivity appeared in evaporated films exposed to air for 1 year. The nature of the impurities in the evaporated film is uncertain because the low temperature of evaporation (<900°C) and the absence of oxidation during the baking cycle militate against free Cd.

V12. Some Notes on the Low Temperature Resistance Minimum. R. W. SCHMITT AND M. D. FISKE, *General Electric Research Laboratory.*—The effect of changing the microstructure of copper and copper-zinc alloys on the low temperature resistivity minimum has been investigated. No evidence has been found to indicate that such changes either produce a minimum or influence a minimum otherwise present. These results do not confirm the proposal of Blewitt, *et al.*[1] that grain boundaries can produce such a minimum. The experiments on copper-zinc alloys also indicate that zinc, as an impurity in copper, is not responsible for causing a minimum. The latter result is contrary to a report of Gerritsen and Linde.[2]

[1] Blewitt, Coltman, and Redman, Phys. Rev. **93**, 891 (1954).
[2] A. N. Gerritsen and J. O. Linde, Physica **18**, 877 (1952).

V13. The Effect of Plastic Deformation on the Surface Resistivity of Copper Wires. J. ARON AND D. KAHN, *Lewis Flight Propulsion Laboratory.*—The change in the surface resistivity of 0.05 cm copper wire resulting when the wire was subjected to an elongation of 10–15 percent was measured by microwave techniques as follows. Five copper wires were first electropolished and annealed 5 hours at 500°C in vacuum. Each wire was successively made the center conductor of an open ended coaxial line[1] which formed part of one arm of an impedance bridge operated around 9600 megacycles. The unbalance of the bridge due to the insertion of the wire was measured as a function of the applied frequency. If the resistivity of the copper wire is directly computed from the average Q, the result obtained is about 20 percent higher than the dc value and this sets an upper limit for the combined effect of the irregularities of the surface of the wire and losses inherent to the coaxial line employed. Immediately after each wire was pulled it was replaced in the cavity and its surface resistivity measured again. In each case, this was found to have become two to three times as large as before. The surface resistivity of these wires subsequently decreased with time while they were held at room temperature indicating that an annealing process occurs whereby the surface approaches its normal state.

[1] A. C. Beck and R. W. Dawson, Proc. Inst. Radio Engrs. **38**, 1181 (1950).

SATURDAY AFTERNOON AT 1:30

Kent 106

(MARCEL SCHEIN presiding)

Cosmic Rays

Invited Paper

W1. Multiple Photon Production in Electron-Positron Annihilstion. S. N. GUPTA, *Purdue University.* (30 min.)

Contributed Papers

W2. Changes in Amplitude of the Cosmic-Ray 27-Day Intensity Variation with Solar Activity.* PETER MEYER AND J. A. SIMPSON, *University of Chicago.*—Both cosmic-ray neutron and ionization chamber intensity observations reveal that the amplitude of the 27-day recurring intensity variation has been changing over an interval of several years. This phenomenon has been studied using ionization chamber data for the period 1936–1946 and neutron intensity data for 1951–1953. The amplitude of the 27 day intensity variation over these years displays minima and a maximum closely related in time to the minima and maxima of the approximately 11 year cycle in general solar activity. Thus, these results provide additional evidence that solar active regions are related to the 27-day cosmic ray primary intensity variations.

* Assisted by the Office of Scientific Research, Air Research and Development Command, U. S. Air Force.

W3. Identity of Shower Particles in Stars in Region 1–2x Minimum Ionization. E. PICKUP AND A. HUSAIN,* *National Research Council, Canada.*—Grain counting and scattering measurements have been made on about 100 long ($\lesssim 12$ mm) shower tracks from cosmic ray stars in photographic emulsion, which was exposed in a O.N.R. "Skyhook" flight. The particles have fallen into π meson, proton, and deuteron groups and one fairly certain K-meson ($m = 960\ m_e$). The results appear to be in generally good agreement with the latest Bristol results[1] indicating few mesons with mass $\sim 1000\ m_e$. The possible presence of other heavy mesons and hyperons will also be discussed.

* National Research Laboratories Postdoctorate Fellow.
[1] C. F. Powell, Nuovo cimento Suppl., **11**, Ser. 9 (1954).

W4. Delayed Disintegration of Nuclear Fragments. W. F. FRY, J. SCHNEPS, AND M. S. SWAMI, *University of Wisconsin.*—Nuclear emulsions, exposed to cosmic rays, and to 3-Bev protons and 1.4-Bev negative π mesons from the Brookhaven Cosmotron, were scanned for double stars where the secondary star appeared to have been produced by a stopped nuclear fragment. Seventeen examples of such double stars were observed out of 29 000 stars produced by 3-Bev protons; 6 such examples out of 7000 cosmic-ray stars, and 1 example out of 200 stars produced by 1.4-Bev π mesons. In one example, the energy release from the breakup of the fragment was measured and found to be 176 ± 3 Mev which is consistent with the decay of a Λ^0 particle bound in a B_s nucleus. The energy release in a second event, which is interpreted as the mesonic decay of a L_i* fragment, is considerably greater than the decay energy of a Λ^0 particle. In most of the remaining cases the connecting track is shorter than 25 microns. These events are consistent with the non-mesonic decay of a bound Λ^0 particle in a fragment of $Z \geqslant 3$.

[1] W. F. Fry and G. R. White, Nuovo cimento **11**, 551 (1954).

W5. Evidence for Gamma Rays from Hyperons or Heavy Mesons Produced by Cosmotron Protons. S. L. RIDGWAY AND GEORGE B. COLLINS, *Brookhaven National Laboratory.**—In the experiment similar to that of Garwin[1] a search was made for gamma emission from downstream of the target, assuming that hyperons or heavy mesons produced in the target in proton-nucleon collisions decaying with lifetime in the $\sim 10^{-10}$ second region may decay by π^0 emission. In two considerably different arrangements with collimators that observed a 2-in. long region downstream, and a gamma-sensitive 20-Mev threshold fast triple coincidence counter at angles of 55° and 90° to the beam, there was observed, at 3 Bev, an intensity of gamma rays downstream of the target that was $\sim 10^{-3}$ of the π^0 gamma intensity of the target, and an energy dependence with a threshold approximately 1.2 Bev, consistant with the hypothesis of associated production. Observing the intensity decrease with target upstream motion, there appears a fast decaying component with mean survival distance between 1.1 and 1.8 cm, and a slower component.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] R. L. Garwin, Phys. Rev. **90**, 274 (1953).

W6. Chi Meson Produced by 3-Bev Protons.* R. D. HILL, *University of Illinois,* AND E. O. SALANT AND M. WIDGOFF, *Brookhaven National Laboratory.*—K mesons have been found in Ilford G5 stripped emulsions exposed to radiations from a copper target bombarded by 3-Bev protons of the Cosmotron. One K meson emerging at 90° to the proton beam was observed to decay at rest 9.4 cm from the target, giving a flat out-going track of 5.25 cm in a single strip. Both the scattering angle and blob density measurements showed significant changes along the outgoing track. On a plot of $p\beta$ *vs* ratio of blob density to plateau density, five equally spaced points, each based on 9 mm of track, fell very closely on the curve determined for pions by Fleming and Lord.[1] Our plateau blob density, determined from $\mu - e$ decay electrons, agreed with that of Fleming and Lord. Identification as a pion was supported by the variation of $p\beta$ with range. Hence this K is a χ^+ meson. The value of $p\beta$ at the start of the outgoing track was (163 ± 10) Mev/c. If one assumes that the χ^+ meson decays at rest into a π_0 (263.7 m_e) and a π^+ (273.4 m_e), then its mass is $(950 \pm 40)\ m_e$ and the Q value of its decay is (211 ± 20) Mev, agreeing with that of the θ^0 meson.[2]

* Work performed under auspices of the U. S. Energy Commission.
[1] Fleming and Lord, Phys. Rev. **92**, 511, (1953).
[2] Thomas, Burwell, Cohn, Huggett, and Karzmark, Phys. Rev. **95**, 661, (1954).

W7. New Evidence Concerning the Specific Identity of the θ^0 Decay Fragments and the Statistics of the θ^0 Particle.* J. R. BURWELL, R. W. HUGGETT, AND R. W. THOMPSON, *Indiana University.*—In view of the preliminary analysis of τ decay by Dalitz,[1] there is indication that the θ and τ mesons may represent different K-particle families. From the point of view of the θ meson, the argument depends essentially on the fact that the two decay fragments are both pions, rather than a pion and a muon. Therefore it may be of interest to report

some new results which favor the two pion scheme. The status of previous evidence on this point is summarized in a recent paper.[2] The new evidence is based on the dynamic methods of analysis which provides means for the absolute determination of parent and fragment masses. In the case of θ^0 decay, the dynamic distinction between pion and muon fragments is difficult since those fragments are quite relativistic in the center-of-mass system. However, a substantial set of decay data from the large Indiana magnet chamber is now available and a straightforward fitting procedure indicates that, to 99 percent confidence level, both fragments are pions. Conversely, assuming equal fragment masses, the best value is 285 m_e, with an error certainly small enough to exclude two muons.

* Assisted by the U. S. Office of Ordnance Research and by grant of the Frederick Gardner Cottrell Fund of the Research Corporation.
[1] R. H. Dalitz, Phys. Rev. **94**, 1046 (1954).
[2] Thompson, Burwell, Huggett, and Karzmark, Phys. Rev. **95**, 1576 (1954).

W8. New Examples of the Anomalous V^0 Particles.* R. W. Huggett, J. R. Burwell, and R. W. Thompson, *Indiana University.*—Since the first resolved example of the anomalous V^0 particle was reported,[1] a limited number of additional examples have been found by various groups. Although the existence of the phenomenon now appears to be firmly established, the nature and decay scheme of the neutral parent particle (or particles) is not yet known. The object of this paper is to report two new V^0 decay events of fortuitous quality and to discuss the relationship of this new data to the previous data and to the various conjectures that have been made as to the decay scheme.

* Assisted by the U. S. Office of Ordnance Research and by grant of the Frederick Gardner Cottrell Fund of the Research Corporation.
[1] Thompson, Buskirk, Etter, Karzmark, and Rediker, Phys. Rev. **90**, 329 (1953).

W9. Evidence for Charge Asymmetry of the $V^{\pm}$ Particles.* Y. B. Kim, J. R. Burwell, R. W. Huggett, and R. W. Thompson, *Indiana University.*—Analyses have been made on 13 V^+ and 18 V^- decays obtained in the large magnetic cloud chamber.[1] The distribution of transverse momentum for V^+ suggests a 2-body decay with $p' \sim 220$ Mev/c, the c.m. momentum. For V^-, the distribution appears broader and the mean is lower. Also, the V^+ lifetime appears longer than that of V^-. Such a charge asymmetry has not been previously observed in the magnetic cloud chamber work. In 3 V^+ events, the values of p' are consistent with a unique $p' = 222 \pm 5$ Mev/c. Thus the present data provide preliminary evidence for a long-lived particle $K^+(\sim 1000\ m_e) \rightarrow L^+ + (\pi^0, \nu, \text{or } \gamma)$. In one V^- event, $p' < 140$ Mev/c; therefore, the V^- data cannot represent 2-body decay of a homogeneous group. In another V^- event, the charged secondary is a π^- ($\pi - \mu$ decay). This event is consistent with $\tau^- \rightarrow \pi^- + 2\pi^0$ or $V^- \rightarrow \Lambda^0 + \pi^-$. However, not many of the V^- events can be attributed to these decay schemes. Also, very few $V^{\pm}$ events can be attributed to $K^{\pm}(\sim 1450\ m_e) \rightarrow \mu^{\pm} + 2\nu$.

* Assisted by the U. S. Office of Ordnance Research and by grant of the Frederick Gardner Cottrell Fund of the Research Corporation.
[1] Thompson, Buskirk, Etter, Karzmark, and Rediker, Phys. Rev. **90**, 329 (1953).

W10. Charged V Particle Production in a Proton-Proton Collision.* M. M. Block† and E. M. Harth,‡ *Naval Research Laboratory*, W. B. Fowler, R. P. Shutt, A. M. Thorndike, and W. L. Whittemore, *Brookhaven National Laboratory.*—A 20 atmosphere hydrogen-filled diffusion cloud chamber, in a magnetic field of 9500 gauss, was exposed to an external 2.6-Bev proton beam at the Brookhaven Cosmotron. A p-p collision was observed in which two positively charged particles, which were not coplanar with the beam track, were produced; one (a), traveled 6 cm and decayed through an angle of 12.5°, and the other (b) went 3 cm, where it appeared to have decayed through an angle of only 2°. The ratio of the ionizations of this track after and before the point of apparent decay was ~1.5–2, which makes the given interpretation quite likely in spite of the somewhat uncertain decay angle. The decay product of b is identified as a proton by momentum and ionization measurements; we assume that b is a hyperon with the decay scheme $\Lambda^+ \rightarrow p + \pi^0 + 115$ Mev. From the kinetics of the p-p collision, particle a is identified as a K particle of $\sim 1000\ m_e$. The reaction scheme, $p + p \rightarrow \Lambda^+ + K^+ + N$, where N is a neutron, is proposed and is internally consistent with our data. This implies that the K^+ meson observed is a boson.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† On military leave of absence from Duke University, Durham, North Carolina.
‡ Now at Duke University, Durham, North Carolina.

Saturday Afternoon at 1:30

Eckhart 133

(D. R. Inglis presiding)

Reactions of Transmutation, II; Neutron-Yielding Reactions, Electric Excitation

X1. Neutrons in Coincidence with Photoprotons.* A. C. Odian, W. Rankin, P. C. Stein, and A. Wattenberg, *M.I.T.*—Further studies have been made at the MIT synchrotron of those neutrons which are in coincidence with high energy photoprotons. A plastic scintillation counter telescope detected protons with an energy spread of about 10 Mev. The neutron detector was approximately 5 percent efficient and had no energy selectivity. Targets of Li, D_2O, and H_2O were employed. The neutrons from deuterium had the kinematically predicted spiked angular distribution when the proton energy and angle were held fixed. With the same proton energy and angle, the neutrons from Li and oxygen came off about the same angle as from deuterium, but with an angular spread whose width depended upon the photon energy. The spread in neutron angle from Li and O had a width at half-maximum of about 50° for 140-Mev photons and about 33° for 252-Mev photons.

* This work was supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

X2. The Angular Distribution of Neutrons from the Reaction $D(d,n)He^3$ at 100 Kev.* J. C. Fuller and D. C. Ralph, *Louisiana State University.*—The relative intensity of neutrons resulting from 100 Kev deuterons incident on a thick deuterated paraffin target has been measured by means of nuclear emulsions exposed at six laboratory angles ranging

from 0° to 150°. The yields in center of mass coordinates agree well with the relation $n'(\theta')=n'(90)[1+A(E)\cos^2\theta']$, and require an asymmetry coefficient $A(E)=0.48\pm0.09$. A comparison of these data with previous results[1-3] in the low-energy region will be made.

* Supported in part by a grant by the Research Corporation.
[1] I. Bartholdson, Arkiv Fysik **2**, 271 (1950).
[2] P. Baker and A. Waltner, Phys. Rev. **88**, 1213 (1952).
[3] Eliot, Roaf, and Shaw, Proc. Roy. Soc. (London) **216**, 57 (1953).

X3. $Li^7(d,n)Be^8$ Neutron Spectrum and Differential Cross Section. C. C. TRAIL* AND C. H. JOHNSON, *Oak Ridge National Laboratory.*—The neutron spectrum and differential cross sections for the $Li^7(d,n)Be^8$ reaction have been obtained at 2-Mev bombarding energy with a neutron spectrometer described previously.[1] The spectrum at 120° indicated only one excited state in Be^8 (at 3 Mev) up to an excitation of 9 Mev in agreement with the 0° data.[1] The neutron angular distributions for the two states were measured by observing the spectrum at fourteen angles from 0° to 135°. Each spectrum exhibited, in addition to the two groups, a continuum which results from the three-body breakup of Be^8. In order to plot the angular distributions, this continuum was subtracted in an arbitrary but consistent manner. Absolute cross sections were obtained by normalizing the yield at 0° to the cross section obtained with a weighed LiF target. The cross section for the ground-state group decreases from 3.2 ± 0.3 mb/steradian at 0° to 1.7 ± 0.2 for angles larger than 40°. That for the 3-Mev state decreases from 6.7 ± 0.7 mb/steradian at 0° to approximately 4.5 mc/steradian for angles greater than 90°. Butler curves for $l_p=1$ give a qualitative description of the forward yield but not of the yield at larger angles.

* Now at argonne National Laboratory.
[1] C. C. Trail and C. H. Johnson, Phys. Rev. **95**, 1363 (1954).

X4. Neutron Yields as a Function of Energy in the Reactions $Li^7(d,n)Be^8$ and $Be^9(d,n)B^{10}$.* D. C. RALPH AND F. E. DUNNAM, *Louisiana State University.*—Neutron yields from the deuteron bombardment of lithium and beryllium have been studied over an incident deuteron energy range of 70–110 kev. Incident deuterons were supplied by a Cockcroft-Walton accelerator, and neutron yields were measured with an anthracene scintillator. Gamow plots of the data give lines with slopes in agreement with the experiments of Sawyer and Phillips[1] on the charged particle yield for these reactions. The theoretical interpretation of these results will be discussed.

* Assisted in part by Research Corporation.
[1] G. A. Sawyer and J. A. Phillips, LADC-1578 (1953).

X5. $Be^9(n,2n)Be^8$ Reaction. J. M. FOWLER, S. S. HANNA, AND G. E. OWEN, *The Johns Hopkins University.**—The $Be^9(n,2n)Be^8$ reaction has been studied at a neutron energy of 3.7 Mev using the $D(d,n)He^3$ reaction as a neutron source. The inelastic neutrons were observed with two large *trans*-stilbene counters operated in coincidence, and the neutron flux was monitored with the protons from the $D(d,p)H^3$ reaction. The pulse-height spectrum from one of the counters was measured with a multichannel analyzer which was gated by coincidences between the pulses from the two counters. The scintillators intercepted a solid angle of 0.114 steradian at the scatterer. In order to obtain the cross section for this process, observations were made in a plane containing the incident neutron at the following pairs of angles: 30°–30°, 60°–60°, 67°–67°, 80°–80°, and 0°–90°. These spectra all showed evidence of two discrete neutron groups, suggesting the mechanism $Be^9(n,n')Be^{9*}(n'')Be^8$. The observed neutron energies indicated an excitation energy of Be^9 consistent with the known value of 2.43 Mev.

* Assisted by a contract with the U. S. Atomic Energy Commission.

X6. Angular Distribution of Gamma Rays from Coulomb Excitation. P. H. STELSON AND F. K. MCGOWAN, *Oak Ridge National Laboratory.*—To test the semiclassical theory of angular distribution of gamma-rays following Coulomb excitation given by Alder and Winther,[1] we have carried out measurements on the 330- and 358-kev gamma rays in Pt^{194} and Pt^{196}. These gamma rays are especially suitable because of the large coefficients for P_2 and P_4 characteristic of 0–2–0 transitions and because angular correlation measurements have shown no observable influence of extranuclear fields. The experimental and theoretical values for the energy-dependent coefficients, a_2 and a_4, for a thick target are listed beneath. The observed energy dependence deviates considerably from the theory. In addition, larger differences have been bound for medium weight nuclei ($Z=40$ to 50), indicating a Z dependence for the energy-dependent coefficients.

Proton energy Mev	(a_2) exp	(a_2) theory	(a_4) exp	(a_4) theory
2.5	$+0.800\pm0.015$	$+0.696$	-0.068 ± 0.010	-0.019
3.0	$+0.709\pm0.010$	$+0.683$	-0.054 ± 0.005	-0.020
3.5	$+0.637\pm0.008$	$+0.667$	-0.023 ± 0.007	-0.022
4.0	$+0.590\pm0.007$	$+0.652$	-0.011 ± 0.004	-0.026
4.5	$+0.534\pm0.015$	$+0.636$	-0.006 ± 0.007	-0.035
5.0	$+0.478\pm0.008$	$+0.623$	$+0.001\pm0.003$	-0.040

[1] K. Alder and A. Winther, Phys. Rev. **91**, 1578 (1953).

X7. Electric Excitation of Heavy Nuclei with Protons.* CLYDE MCCLELLAND, HANS MARK, AND CLARK GOODMAN, *M.I.T.*—The low-lying energy levels of seventeen heavy nuclides, including isotopes of hafnium, tantalum, wolfram, rhenium, and platinum have been studied by electric excitation with protons.[1,2] The results have been interpreted in terms of the hypothesis of nuclear rotational levels of Bohr and Mottelson.[3] Approximate intrinsic electric quadrupole moments (Q_0) have been determined for these nuclides from the energies and electric excitation cross sections of the various levels. The values of Q_0 obtained by these two methods are in good agreement for isotopes of highly deformed nuclei (hafnium) but as the shell at 126 neutrons and 82 protons (Pt^{198}) is approached the value of Q_0 obtained from the excitation energy exceeds the value obtained from the cross section by a factor of seven.

* Supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] T. Huus and C. Zupancic, Dan. Mat. Fys. Medd. **28**, No. 1 (1953).
[2] C. L. McClelland and Clark Goodman, Phys. Rev. **91**, 760 (1953).
[3] A. Bohr and B. R. Mottelson, Dan. Mat. Fys. Medd. **27**, No. 16 (1953).

X8. Electric Excitation of Nuclei Near the Closed 50 Proton and Neutron Shells.* HANS MARK, CLYDE MCCLELLAND, AND CLARK GOODMAN, *M.I.T.*—Energy levels of several nuclei near the closed 50 proton and neutron shells have been studied by electric excitation with protons. Two elements (zirconium and niobium) near the closed 50 neutron shell have no energy levels which have large electric excitation cross sections. Several nuclei (palladium, silver, cadmium and iodine) near the closed 50 proton shell have levels with large electric excitation cross sections. The 325- and 436-kev γ rays from natural silver, which are due to levels of nearly equal energies[1] in Ag^{107} and Ag^{109}, have been studied in detail using thick and thin targets. The yield of these γ rays as a function of proton energy agrees well with the electric quadrupole excitation function between 1.5 and 3.5 Mev. Reduced electric quadrupole transitions probabilities obtained from excitation cross-section measurements for levels in palladium, silver, cadmium and iodine are smaller by factors of ten to fifty than those obtained from the energies of the transitions assuming rotational excitation.[2]

* Supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] N. Heydenburg and G. Temmer, Phys. Rev. **95**, 861 (1954).
[2] A. Bohr and B. R. Mottelson, Dan. Mat. Fys. Medd. **27**, No. 16 (1953).

SATURDAY AFTERNOON AT 1:30

Cobb 110

(A. H. WEBER presiding)

General Physics, II

Y1. Some Tabulations of Cosmic Abundances. J. Y. SMITH, *The Ohio State University.*—Tentative values of cosmic abundance are assigned to 286 natural nuclear species, after correlating published data on abundance values for 83 elements and multiplying each value by an isotopic percent. Differing tabulations are assembled with each of 285 nuclides (excluding hydrogen-1) identified by proton, neutron, mass, and isotopic number and by an abundance value which is the prime criterion of tabulation. One table ranks in order of abundance the 285 nuclides with P, N, M, I, and abundance values, and additionally for each nuclide, an index as stable or unstable and with or without isomeric states. Another table comprises four columnar sets with the nuclides alternatively grouped under 121 N numbers, 210 M numbers and 50 I numbers along with the initial 83 P numbers. Abundance value for a P, N, M, or I number is the sum of values for nuclides having that number (isotones, isobars, etc.). After ranking each columnar set by abundance, with a counting of the nuclides bearing each number, all four sets are assembled for inspection of possible coincidences or near-coincidences across the rows of the same relative abundance rank. A third table illustrates alterations in such horizontal alignments, and in vertical clusters, arising from differing methods for initial evaluations of abundance.

Y2. The Branching Ratio of K^{40} and the Age of Meteorites. G. J. WASSERBURG, *University of Chicago,* AND R. J. HAYDEN, *Argonne National Laboratory.*—The A^{40}/K^{40} ratios and the Pb^{206}/U^{238} and Pb^{207}/U^{235} ages of various coexisting potassium feldspars and uraninites were determined. The argon was released from the minerals by fluxing with NaOH at 600°C. The radiogenic A^{40} content was determined using an isotopic dilution technique. A^{38} was used as a tracer. The branching ratio was calculated assuming the Pb−U age and using a decay constant $\lambda = 0.55 \times 10^{-9}$ yr^{-1}. The Pb^{206}/U^{238} and Pb^{207}/U^{235} ages determined agreed within 2 percent for each sample investigated. Nine samples ranging in age from 2.7×10^8 to 1.9×10^9 yr were run. The value obtained for the branching ratio was $\lambda_\epsilon/\lambda_\beta = 0.085 \pm 0.005$. No systematic decrease in the branching ratio was observed with the age of the sample indicating no significant loss of argon due to diffusion. The A^{40}/K^{40} ages of two stony meteorites were determined using the method described. An isotopic dilution technique was used to determine the potassium content. K^{41} was used as a tracer. The isotopic ratios were determined by a surface ionization technique using a mass spectrometer with 60° deflection and a 12-inch radius of curvature. The following ages were obtained: Beardsley, $4.82 \pm 0.2 \times 10^9$ yr, Forest City $4.58 \pm 0.2 \times 10^9$ yr.

Y3. Potassium-Argon Ages of Lepidolites. G. W. WETHERILL, L. T. ALDRICH, AND G. L. DAVIS, *Carnegie Institution of Washington.*—The radiogenic argon content of several lepidolites has been determined by a mass-spectrometric isotopic dilution technique, using A^{38} as a stable isotope tracer. Potassium analyses were made with a flame photometer. Using the decay constants $\lambda_{\beta^-} = 5.06 \times 10^{-10}$ yr^{-1} and $\lambda_\epsilon/\lambda_{\beta^-} = 0.090$ the following ages have been calculated and compared with Rb−Sr ages on the same mineral specimens.

Sample	K−A age	Rb−Sr age
Bikita, S. Rhodesia	2750	3400
Bonneville, Wyoming	2570	3020
Bagdad, Arizona	1610	1900
Ohio City, Colorado: White	1500	1740
Coarse	1540	1750

The potassium-argon age of Bikita lepidolite agrees with reliable uranium-lead and thorium-lead ages of a monazite sample from this locality. The argon content of the atmosphere has been found to be 0.93_4 percent by this same technique, in excellent agreement with earlier volumetric analyses.

Y4. Low-Energy Electron Diffraction Studies of a Germanium Crystal Surface. H. E. FARNSWORTH, R. E. SCHLIER, AND R. M. BURGER, *Brown University.**—A beam of primary electrons at normal incidence in the energy range below 250 ev is diffracted from an etched (100) crystal face. Because of the low penetration, surface contamination is easily detected. Attempts to clean the crystal surface by prolonged outgassing in a high vacuum near the melting point were unsuccessful, although some weak diffraction beams from the germanium crystal were observed, thus indicating that the adsorbed gas layer had been reduced very appreciably in thickness. However, after subsequent bombardment of the crystal surface by argon ions in a low pressure discharge, followed by a very short annealing (a few minutes at 500°C), intense, sharp diffraction beams characteristic of a germanium lattice were observed in the two principal azimuths. The manner in which residual gas was later adsorbed is discussed. Some anomalies in the diffraction pattern are described. Studies of controlled adsorption of various gases are in progress.

* Assisted by Project Lincoln, U. S. Air Force.

Y5. Low-Energy Electron Diffraction Studies of a Titanium Crystal Surface. R. E. SCHLIER, H. E. FARNSWORTH, AND T. H. GEORGE, *Brown University.**—A primary electron beam in the energy range below 250 ev is incident normally on an etched (0001) crystal face. After prolonged outgassing in a high vacuum at temperatures up to 750°C (the transition point is at approximately 850°C), intense sharp diffraction beams were observed which are not characteristic of the titanium lattice. Subsequent bombardment by argon ions in a low-pressure discharge removed the surface layer which produced this diffraction pattern. Damage to the crystal lattice caused by ion bombardment was removed by a very short annealing (a few minutes at 500°C), after which an intense sharp diffraction pattern characteristic of the titanium surface lattice was observed in the two principal azimuths. This diffraction pattern was not obtained by ion bombardment unless the crystal had been outgassed previously by heating at 700°C to 750°C for many hours. Observations on the subsequent adsorption of residual gas is described. Certain anomolies in the diffraction pattern have been observed. Studies of controlled adsorption of various gases are in progress.

* Assisted by Office of Ordnance Research, U. S. Army.

Y6. Measurement of Ionizing Radiation by Frequency Variation Using Ferroelectric Material. HANS KOHN RICHARDS AND EUGENE D. DENMAN, *Oak Ridge National Laboratory.*—A method of measuring ionizing radiation by frequency variation was reported at the American Physical Society Meeting, November, 1952. At that time, the frequency variation of an oscillator was produced by a moving vane electrometer as the reactance elements. To eliminate moving parts, the electrometer has been replaced by a ferroelectric capacitance. Barium titanate ($\frac{1}{2}$ mm thick, area one mm^2) silverplated on opposite

sides had capacitance values between 10 and 15 $\mu\mu$F. This capacitance was connected to a similar one and also to the center electrode of an ionization chamber. Both were in series as elements of the frequency determining network of an oscillator, but connected electrostatically in parallel. The center electrode and connected capacitance areas were charged to 200 to 300 volts. The ferroelectric capacitance decreased with increase in charge and therefore the oscillator frequency increased. The oscillator was controlled by a 2 megacycles quartz crystal which permitted a frequency variation of several thousand cycles/sec. The sensitivity, limited by the finite leakage resistance of the material, permitted measurements of dose rates as low as 10 mr/hr. This limitation was minimized by measuring the beat frequency of identical oscillators, one of which was connected to the ionization chamber, thus the sensitivity was extended to lower values.

Y7. Duration of Mercury Arcs in Evacuated Bulbs Coated with Rare Earths. B. PEARSON DE LANY AND PAUL L. COPELAND, *Illinois Institute of Technology.*—Previous experiments[1] have shown that the distribution of observed durations for the low pressure mercury arc is exponential when the cathode spot is unanchored or when it is anchored at one point of the junction between a tungsten-coated wall and the mercury pool. In the present study interior surfaces of experimental tubes were coated with rare earths obtained by heating misch metal in vacuum. Added mercury wet the coated wall, and the cathode spot after several minutes of operation ordinarily was confined to points on the junction between the mercury pool and the film. The position of the spot changed from time to time. For a given mode of anchoring an exponential distribution of lives would be expected, but the decay constant for the distribution varies from point to point along the curve of contact. In this case, a simple exponential distribution of the observations is not obtained. There are too few observations in the middle range, and the distribution is characterized by occasional observations of very long arc duration.

[1] P. L. Copeland and W. H. Sparing, J. Appl. Phys. **16**, 302 (1945).

Y8. Statistics of the Exponential Distribution of Exponential Populations Applied to the Distribution of Arc Lives. PAUL L. COPELAND AND B. PEARSON DE LANY, *Illinois Institute of Technology.*—As a means of describing the observed distribution of arc lives in rare-earth-coated, mercury arc tubes, certain statistics of exponential populations, $\exp(-t/l)dt/l$ continuously distributed in average life according to the law $dN=-kdl\exp(-kl)$, where l represents the average duration of simple exponential constituents, have been computed. For the same expected duration, $1/k$, the statistical fluctuation of individual observations is three times as large as for the simple exponential. This combination of exponentials gives many more small observations, and the number of individuals surviving many times longer than the average is several orders of magnitude greater than for the simple exponential distribution. The proportion of individuals surviving until time T as computed from

$$p=\int_0^\infty kdle^{-kl}\int_T^\infty e^{t/l}\frac{dt}{l}$$

$$=\int_0^\infty kdle^{-(kl+T/l)}$$

is compared with experimental results from a series of 1000 observations.

Y9. Evapor-ion Pump Developments.* MELVIN J. BINA, IGOR ALEXEFF, AND RICHARD M. SANDERS, *University of Wisconsin.*—Further advances have been made with the Evapor-ion pump[1] which utilizes both gettering and ionization pumping to reach pressures down to 5×10^{-6} mm Hg. Titanium wire is fed onto a heated post, evaporates, and condenses on the pump wall, where gettering occurs. The ionization system, now much improved, pumps inert gas atoms by ionizing them in an electric field and driving them into the ever increasing titanium layer on the pump wall. Argon is pumped at 160 liters/sec at 7.2×10^{-6} mm with a pump power input of about 3 kw. Chemically active gases are pumped at about 10^4 liters/sec. Operating time at present is limited either by erosion of the post by molten titanium or deposits upon it. The lifetimes of several post materials have been compared. In starting, pressure in the pump is reduced from forepump level to below the threshold of glow discharges by use of a primer, a tungsten wire from which a small amount of titanium is evaporated by conduction current heating.

* Work supported by the Wisconsin Alumni Research Foundation, the U. S. Atomic Energy Commission, and the National Science Foundation.
[1] Divatia, Davis, and Herb, Phys. Rev. **93**, 926 (1954).

Y10. A Physical Theory for Capillary Flow. E. E. MILLER, *University of Wisconsin.*—The motion of fluids which incompletely fill the voids between the solid grains of a porous medium (exemplified in the action of a blotter) has important technological applications in soils, petroleum extraction, chemical engineering, etc. The problem is complicated by marked hysteresis effects in the dependence of the flow properties of the medium upon liquid content. By assuming that the gas-liquid interface shapes within the pores are governed by the standard differential equation of surface tension, and that the flow within the tortuous microscopic channels obeys the differential equation of viscous flow, a nonlinear differential equation for macroscopic flow is deduced. This equation is obtained in fully reduced form and exhibits hysteresis in an interesting and simple way. The reduced variables, deduced from the similitude properties of the basic differential equations, provide several direct predictions susceptible to experimental test. They also suggest useful applications such as scale modeling of systems, reduction of the essential diversity of medium types, etc. Although little of the experimental work already in the literature provides information on the applicability of this theory, that which does so appears to be favorable.

Y11. On the New Fundamentals of Fluid Dynamics. M. Z. v. KRZYWOBLOCKI, *University of Illinois* (introduced by C. E. MANDEVILLE).—The author points out that fundamentally the mechanics of continuum can give correct answers in the case of incompressible media. Application of continuum equations to compressible media gives answers to the first approximation only. Principally, the phenomena in gases should be considered on the basis of the statistical mechanics due to the physical structure of a gas. The approach from the kinetic theory point of view is obvious. Some remarks on the mathematical part of the problem, like ergodic theorem, invariant measure, etc., close the presentation.

Y12. Field Effect of Space Charge in the Intermittent Glow in Hydrogen. HERMAN RITOW.—Gill, Mitra, and Clark found that the effective tube capacity during discharge was many orders larger than that caused by the geometry of the tube and electrodes. Two methods are developed for measuring the charge on the electrodes at the moment of flash initiation. This charge is shown experimentally to be approximately 10^{-7} coulombs for each square centimeter of the smaller of the two electrodes. This means the electrostatic field at this electrode is of the order of 10^6 volts per cm. Since the emission field of the electrode metal is of the same order, the possibility exists that field emission plays a role in initiating a flash along with photoionization and exponential avalanche formation.

SATURDAY AFTERNOON AT 1:30

Mandel Hall

(ARNOLD NORDSIECK presiding)

Invited Papers

Z1. Hyperfine Splitting in Electron-Spin Resonances of Donors in Silicon. R. C. FLETCHER, *Bell Telephone Laboratories.* (30 min.)

Z2. Theory of the Hyperfine Splitting of Donor States in Silicon. WALTER KOHN, *Bell Telephone Laboratories and Carnegie Institute of Technology.* (30 min.)

Z3. Recent Developments in the Effective-Mass Theory for Semiconductors. J. M. LUTTINGER, *Bell Telephone Laboratories and University of Michigan.* (30 min.)

SUPPLEMENTARY PROGRAMME

SP1. Quantized Spin Paramagnetism in a Free Radical Near Magnetic Saturation. WARREN E. HENRY, *United States Naval Research Laboratory.**—Paramagnetism of free radicals was predicted[1] on the basis of the existence of an unpaired, bound electron and then experimentally confirmed[2] by susceptibility and microwave resonance measurements. However, despite the spin-only g value and negligible spin-orbit coupling of the Banfield and Kenyon free radical, its use in adiabatic demagnetization is impaired by exchange interaction. Diphenyl picryl hydrazil, the subject of this investigation, is more magnetically dilute. We have carried out magnetization experiments in the range, 1.3° to 4.2°K and in magnetic fields up to 50 000 gauss. The magnetic moments were determined ballistically as the sample was moved relative to a coil system.[3] The magnetization, when plotted against H/T, gives isotherms (at 1.3°, 2.0°, 3.0°, and 4.2°K) which superpose. They fall on a Brillouin function for $g=2$ and $J=S=\frac{1}{2}$. Our results are in general agreement with the Leiden[4] work at low fields, except that at the lower temperatures, we do not observe a drop in $M(H/T)$. The measurements confirm the smallness of exchange interaction and indicate some usefulness of diphenyl picryl hydrazil as a paramagnetic coolant.

* To be given at the end of Session C if the Chairman rules that time permits.

[1] N. W. Taylor and G. N. Lewis, Proc. Nat. Acad. Sci. **11**, 456 (1925).
[2] Garstens, Singer, and Ryan, Phys. Rev. **96**, 53 (1954); J. Kenyon and S. Sugden, J. Chem. Soc. 170 (1932); Holden, Kittel, Merritt, and Yager, Phys. Rev. **75**, 1614 (1949).
[3] W. E. Henry, Phys. Rev. **88**, 559 (1952).
[4] Gerritsen, Okkes, Gijman, and van den Handel, Physica **20**, 13 (1954).

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Crosbie, E. A. and M. Hamermesh—I5
Chraplyvy, Z. V.—U4
de Lany, B. Pearson, and Paul L. Copeland—Y7
Dumke, William P.—G12
Delbecq, C. J., P. Pringsheim, and P. H. Yuster—P5
Ekstein, Hans and Norman Rostoker—A2
Enck, F. D. and C. B. Cooper—P7
Engel, O. G.—P2
Farnsworth, H. E., R. E. Schlier, and R. M. Burger—Y4
Faust, W. R., V. E. Scherrer, and B. A. Allison—B6
Feiner, F., J. Ashkin, J. P. Blaser, and M. O. Stern—Q6
Feld, Bernard T.—Q1
Ferentz, M. and N. Rosenzweig—A6
Fiske, M. D.—T4
Fletcher, R. C.—Z1
Ford, K. W.—U3
Fowler, J. M., S. S. Hanna, and G. E. Owen—X5
Frankl, D. R.—P15
Frye, G. M., Jr., A. H. Armstrong, and L. Rosen—R2
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Grimsal, E. G.—G8
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Hill, R. D., E. O. Salant, and M. Widgoff—W6
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Kerr, J. and C. Wert—C2
Kerst, D. W.—L2
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Kisslinger, Leonard S.—Q5
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Maxson, D. R., J. S. Allen, and W. K. Jentschke—H2
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Robinson, John E.—E3
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Skolnik, W.—Q9
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Turner, C. M.—I10
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Wilkinson, D. H. and A. M. Lane—K7
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Yuster, Philip, Sol Rocklin, Warren Ramler, and Charles Delbecq—I6
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